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CONCENTRATING ORES BY FLOTATION

BEING A DESCRIPTION AND HISTORY OF A RECENT METALLURGICAL DEVELOPMENT, TOGETHER WITH A SUMMARY OF PATENTS AND LITIGATION.

BY
THEODORE J. HOOVER
A.B., Leland Stanford Jr. University,
Member of American Institute of Mining Engineers,
Member Institution of Mining and Metallurgy,
Member Société Belge des Ingénieurs et des Industriels,
Member Société des Ingénieurs Civils de France.

THIRD EDITION

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1916

To the Teachers of Science in Leland Stanford Jr. University
who gave me the desire to know and to learn.

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PREFACE TO FIRST EDITION.

This book is intended as an interim report of progress in a rapidly developing art. It is put forward in the hope that it may prevent duplication of labour on the part of ambitious inventors, and that it may give engineers not already familiar with the subject a starting point in the application of a new method of turning ores to account.

My debt to the labour and assistance of others can hardly be acknowledged adequately. To the directors of Minerals Separation, Ltd., cordial thanks are due for permission to publish much information collected during four years while acting as their general manager and consulting engineer. Although this permission is kindly granted, they are not necessarily in agreement with all the opinions expressed, and, in fact, quite properly oppose some of the views set forth.

To H. Livingstone Sulman and Hugh F. K. Picard, of the firm of Sulman & Picard, I am indebted for many ideas absorbed from them through three years of pleasant professional association (during which time they were consulting metallurgists to the above company). They have in preparation a book on the 'Theories of Concentration Processes Involving Surface Tension,' which will be a work of high scientific merit. I have endeavoured, I hope successfully, not to trespass on any new and unpublished ground, the announcement of which rightfully belongs to them; further, it is not my desire to present the subject in so profound a manner as they will do, deeming it of considerably more use to engineers to leave for another occasion the discussion of the mathematical and physical laws involved.

To the members of my former staff and others, Deane P. Mitchell, James M. Hyde, James Hebbard, E. J. Horwood, Henry Lavers, Edward H. Nutter, George W. Thompson, H. H. Greenway, A. Howard Higgins, George A. Chapman, A. Sydney Stevens, E. Ray Wilkinson, Alfred K. Burn, A. C. Howard, George C. Klug, C. J. Hylton, John Leechman, F. Glynn Price, and E. E. Wood, I am indebted to an extent that the mere mention of their names but scantily requites.

The files of the current technical journals and financial papers have been drawn upon with a free hand; these receive individual acknowledgment in the bibliography.

THEODORE J. HOOVER.

London, *July* 4, 1912.

PREFACE TO THE SECOND EDITION.

The art of concentrating ores by flotation has developed so rapidly that the first edition of this book was out of date before it was placed on sale. Several years' delay in arranging for its publication, with the attendant discussions and compromises, also provide further justification of an early re-casting of the subject matter. Many new facts have come to hand, and in the light of those facts the author has modified his views in regard to certain patents.

THEODORE J. HOOVER.

London, *April* 14, 1914.

PREFACE TO THE THIRD EDITION.

The advance in the use of flotation processes has been remarkable since the publication of the second edition of this book in 1914. It is with no little satisfaction that the author recognizes that a very considerable part of this advance has been due to the general diffusion of knowledge in regard to these processes by the circulation of the first and second editions. They have enabled metallurgical investigators in widely separated districts to begin and carry on research with energy and intelligence, unhampered by futile experiments in the first lessons of the art. This rapid development has been a great advantage to the patentees and owners of processes, inasmuch as the tonnages treated and royalties collected have been thereby increased.

Long before the second edition was exhausted the publishers informed the author that they had under-estimated the demand, and that a third edition would certainly be required if all the orders for the book were to be filled, and careful consideration was given as to the form this revision, if any, should take. Letters were received from metallurgists in widely scattered districts, expressing profound appreciation of the help they had received from the book, and the conclusion was arrived at that one of the chief merits of the book was that it was a document contemporaneous with the scientific evolution of the art it deals with. It was decided, therefore, to re-publish the text of the second edition intact, with Chapter XIII. added to cover briefly the progress made during the years 1914–16. The developments during these two-and-a-half years have, however, been so large that it is impossible to discuss in such detail as previously all the cases of application. A record of general lines of advance must suffice, leaving detailed discussion for the technical journals and for a younger and wiser generation.

THEODORE J. HOOVER.

London, *June* 14, 1916.

CONCENTRATING ORES BY FLOTATION.

CHAPTER I.

Historical Sketch.

The ores of the base metals when taken from the earth contain the valuable portion in chemical combination, generally with sulphur, in the form of particles of metallic sulphide, mixed with a large quantity of worthless rock. The ore is first crushed to a suitable degree of fineness, in order to free the sulphide particles from the adhering gangue, and the crushed mass is then subjected to mechanical operations with a view to separating all the sulphide particles into one pile, and all the worthless gangue into another pile. The sulphides are then smelted to recover the metals. The oldest method of accomplishing this separation is by mixing the crushed ore with sufficient water to form a freely-flowing pulp, and then subjecting the pulp to a shaking, throwing, and flowing motion, on suitable machines, whereby the sulphide particles, being much heavier than the gangue, travel faster and farther than the gangue, and are diverted at the proper time and place to effect a separation. This method is ancient, and was the only one known for hundreds of years.

A second method, introduced not long ago, made use of the magnetic qualities of the valuable minerals. These in general have a stronger magnetic permeability than the gangue, and if the ore is suitably subjected to the influence of powerful magnets, the valuable mineral particles can thereby be separated from the worthless gangue.

These two methods have limitations as to their usefulness, and these limitations have been a constant spur to metallurgists, urging them to the discovery of new modes of treatment.

The knowledge that substances heavier than water would, under suitable conditions, float on its surface, is not at all new, the best known example being that of a greased needle carefully placed on water. It has been known also for many years that some heavy substances will float on the surface of water with more certainty than others, and the principles involved in this fact formed the basis of a third method of separating mineral sulphides from gangue, as soon as it was recognized that the sulphides would float with greater facility than the gangue. The successful concentration of ores by causing the metallic sulphides to float at the surface of a liquid, and the gangue or waste rock to sink within, with entire disregard of relative specific gravities or magnetic qualities, has now not only overcome the suspicious novelty of its earlier phases, but has an established and growing position in the metallurgy of the base metals. The progress of the practical application of this principle has been so great during the past twelve years as to place it now among the sure expedients of the metallurgist. To the minds of those who have had occasion to apply the process it seems almost as great an advance in the dressing of base-metal ores as the cyanide process proved to be in the recovery of the precious metals. In the recovery of zinc sulphides, especially from the by-products of lead milling, and also of finely disseminated copper sulphides from silicious gangues, it has already a wide field in instances where other methods were of imperfect application, and the range of its application is daily being widened.

A new metallurgical process never springs fully developed from the brain of one person, but is the result of patient investigation, application, and improvement by many minds, during many years. Metallurgical advances can best be likened to the construction of a pyramid by the constant addition of material. The erection of such structures can never be credited to a single person. The first stones are usually laid by those who had an imperfect vision of the structure that would arise, and while many builders come into prominence from year to year, many stones are laid by unknown hands. No builder need flatter himself that he has completed the structure by placing a peak stone in place, for while he is in the very act, it is quite likely that an ambitious newcomer has begun a dozen new courses of masonry at the base of the pyramid. Unfortunately, besides the question of individual credit, there also enters the more serious one of ownership of parts of the structure. Constructive work may be entirely suspended while the courts adjudicate the rights of rival claimants; the completion of the structure is delayed; the time and means of the builders are wasted; and the needs of the industry suffer. The names of those who are known to have helped in this case are Haynes, Tunbridge, Miss Everson, Hebron, Bradford, Dodé, Sutton, Robson, Crowder, the Elmore brothers, Potter, Delprat, Van Meter, Boss, Haultain, Stovel, Froment, Scammell, Cattermole, Goyder, Laughton, Wolf, Sulman, Picard, Ballot, De Bavay, Darling, Gillies, Kirby, Macquisten, Sanders, Schwarz, Chapman, Kendall, Latimer, Hoover, Norris, Higgins, Lockwood, Samuel, Greenway, Horwood, Wentworth, Lavers, Nutter, Hyde, Hockley, Rouse, Maleczek, Allen, Wynne, Dick, Ruthenburg, McCourt, Orr, Good, Wood, Bradford, Owen, Lyster, Schick, Terry and Tucker.

Tardy justice demands that among those who builded better than they knew, the name of Carrie J. Everson, an American schoolteacher, and an assayer and chemist of ability, should be specially mentioned, because she discovered and enunciated the main and fundamental principles upon which all subsequent work has been based.

The development of this important department of metallurgy can be divided roughly into three periods. During the first of these, 1860 to 1902, there were brought forward at least a dozen methods for causing sulphides to float on an ore-pulp, and these methods fell into two principal classes, although some of these patents could not properly be placed in either class and there were even then some inventions which combined elements of both classes.

(1). Those depending on the selective action of oily substances for sulphide particles to entrap the sulphides, and the buoyancy of the oily substance to effect flotation.

(2). Those depending on the selective action of gas for sulphide particles, which under certain conditions endowed the particles with a gaseous envelope, and so induced flotation.

Neither of these ideas when used independently produced entirely satisfactory results, although they were not without some commercial profit.

The second period, from 1902 to 1907, was marked by a practical advance, when the idea was practically and thoroughly developed of endowing the particles with an oily adhesion in an acid solution, thus increasing their affinity for the gaseous envelope, and then bringing the oiled particles into contact with gas bubbles. This combination of the two fundamental ideas of the preliminary stage has made it possible to secure a high degree of flotation among many sulphides. These two periods belong primarily to the inventor, the so-called unpractical man.

The third period, 1907 to 1914, in which we now are, is the stage of the engineer : the commercial application of the idea. Suitable mechanical devices had to be invented to produce the proper mixture of gases, liquids, and solids, and to entrap the concentrate when afloat. This period has now reached so practical a development as to find widespread commercial application.

The different methods have been developed along several lines parallel to each other, so that it is difficult to discuss them as a whole chronologically. They will, therefore, be considered separately in the order of their first appearance.

HAYNES.

William Haynes, an Englishman, in 1860 invented a process for separating mineral sulphides from the gangue or rocky constituent of an ore by the use of oily, gummy, or bituminous matter. This was not a 'flotation' process, but must be considered the pioneer movement in that direction, as Haynes recognized the fact, all important in later developments, that oily substances have a greater affinity for sulphides and metals than they have for oxides and earthy substances. No commercial application of this invention is known to have been attempted.

BRADFORD.

Hezekiah Bradford, an American, in 1886, invented a process of concentration based on 'surface tension' factors, but no commercial application of the idea is known to have resulted. His patent is an important and interesting one, because the flotation of sulphide particles on the surface of a liquid at rest is clearly set forth. He clearly anticipated the inventions of the early De Bavay and Wood type.

EVERSON.

Carrie J. Everson, an American, in 1885, invented a process for separating the sulphides in an ore from the gangue. She made use of the selective action of the oil for sulphides, discovered by

Haynes, and also the "flotation" quality discovered by Bradford, but she also carried the idea two steps further. She discovered—(1) that acid, added in small quantity to the pulp, greatly increased the selective action of the oil; and (2) that the oiled mineral could be separated from the gangue by a thorough agitation of the mass, and by allowing the sulphides to float to the surface as a scum, while the gangue escaped at the bottom of the vessel. The amount of oil used is variously stated in certain experiments as 6%, 12%, and 20%; the amount of acid was less than 1%. It is worthy of note that none of the quantities of oil specified are sufficient to effect the flotation of the sulphide contents of the ore by the buoyancy of the oil alone, and the flotation must, therefore, have been effected by some other means. The means whereby this flotation was accomplished was probably the inclusion of large quantities of air bubbles as a result of the thorough agitation specified. The new principles disclosed in this patent were that acid increases the selective action of the oil, and that minerals can be separated from each other by establishing conditions such that some will float and others will sink. Miss Everson stumbled across the idea quite accidentally.[1] Some sacks in which concentrate had been shipped to her brother's assay-office at Denver had become greasy, and in the process of washing the sacks, the germ of the idea of oil-flotation came under her observation. Attention should be directed to the fact that this invention is strictly feminine in its origin. No masculine assayer probably ever did or ever will launder sample-sacks or ore-bags; when they have reached the condition in which they need washing and where simple shaking does not make them available for further use, they are discarded. When she had the greasy concentrate-sacks in the wash-tub and gave them such agitation as was incident to the operation of washing, it only required the customary acuteness of observation of the Western lady school-teacher to grasp the essential facts of sulphide flotation. This process was tried on a fairly large scale at Baker City, Oregon, in 1889, and also near Denver in the same year. A capitalist of the name of Thomas F. Crilley financed the undertaking. In the process as tried at Baker City, under the name of the Crilley & Everson process, the ore was crushed to 50-mesh, weighed, and roughly mixed with a thick black oil. Boiling water, containing enough acid to give it a tart taste, was then added to the ore.[2] A thick scum of mineral and oil rose to the surface, and was skimmed off,[3] leaving the gangue at the bottom of the vessel.[4] This process was improved in 1892 by Hebron and Everson, whereby they combined pulverized ore with a buoy-stock in a dry state, and then submitted the prepared ore to a stratifying apparatus into which air could be introduced for the purpose of producing effervescence. This word effervescence commands instant attention. Effervescence is a simple and well-understood physical fact, and means simply the ebullition and frothing due to the escape of bubbles. These bubbles were of air, and were rising to the surface in the presence of oiled sulphides in an acid pulp.

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[1] *Financial Times*, March 3, 1902.

The newspaper accounts of the attempts to apply this idea give one a strong impression that if the invention had been a less startling innovation it would probably have received more attention from engineers and metallurgists, and the application of the idea would probably in that case have taken place many years before it did. The competition for ores and products was also less keen at this time than later, and there was, therefore, not the incentive there is today to turn refractory ores to account. It is certain that this invention failed, not because it did not describe and contain all the essential principles of successful flotation concentration, but because those skilled in the art looked at it askance, and it failed of commercial application because it had no serious attempt at mechanical working.

No further definite commercial advance was made, and nothing more was heard of concentration by flotation until 1894.

ROBSON & CROWDER.

In 1894 Robson & Crowder, two Englishmen, invented a process for separating sulphides from gangue; they made use of the idea of oil-selection, but they did not recognize the benefit of acid in increasing this selective action, as Everson had done. Their invention differed from former similar ones in that they used but little water; they say, 25% to 30%. They mixed the ore and the water in a vessel having a suitable agitator, added the oil at the bottom of the vessel during agitation, and allowed it to overflow.

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[2] *Eng. & Min. Jour.*, Nov. 15, 1890, p. 581.

[3] *The Denver News*, Nov. 2, 1889, quotes a description from the *Herald-Democrat*.

[4] *Alta Californian*, Dec. 2, 1889.

Presumably, after a time, the oil had selected and carried over all the sulphides, leaving the gangue, mixed with oil and water, in the bottom of the vessel, from which it could be drawn off. The process was tried at the Glasdir mine in Wales on a fairly large scale. It was at this mine that Elmore later developed his idea of oil-flotation. In April, 1896, James Brothers made for a client a careful examination of the plant and process, and reported that the process was worthy of development, as it seemed adapted to a large class of ores at that time untreatable by other processes. Nothing material came of this effort, however, and the idea lay dormant until 1898, when F. E. Elmore advanced it apace.

ELMORE (OLD PROCESS).

Francis E. Elmore, an Englishman, in 1898 invented a concentration process that involved the idea of oil selection and the idea of flotation in a freely flowing acid pulp. He mixed the ore with several times its weight of water, and an equal, or several times greater, weight of oil in a revolving drum,* so constructed and operated as to give a mixing effect without breaking up or emulsifying the oil, which was added with the ore. He did not mention the amount of oil used, but from the fact that he described in his patent a pump for the oil and a centrifugal apparatus for separating the concentrate from the oil, it is inferred that the amount of oil used was considerable. After thus gently mixing, the mass was allowed to run into a spitzkasten, where the oil carried the sulphides to the surface, and the gangue and the water were removed from the bottom. This invention marks a decided advancement in flotation-concentration, and was put into operation in a workmanlike manner.

This process had commercial application on a large scale. It was in the hands of capable engineers, who were not oblivious to its imperfections, and who appreciated the fact that no one process is ever a cure for all the troubles incidental to the treatment of ores. They tried consistently to adapt the process to suitable ores, and where they made mistakes, these were only such as must be made when development along new lines is attempted. This process was the first of the kind to approach commercial success, and it was a commercial success in many places; but further improvements in flotation-concentration have rendered the method obsolete.

**Trans. I.M. & M.*, Vol. VIII., p. 379-395, Chas. M. Rolker.

The process was tried by the Boston Consolidated Co., Cape Copper Co., and Namaqua Copper Co.[1] The United States rights were[2] purchased by Charles Butters, who tried it on the ore of the Mammoth Mining Co., Utah.[3] Companies were organized in Canada,[4] Great Britain, Sweden, Australia,[5] and plants were built in Norway, England, and in British Columbia on the Le Roi mine. The Le Roi plant had a long series of vicissitudes, and was finally closed down.[6] Plants were built at Tywarnhaile[7] in Cornwall, at the Sygun mine in Wales,[8] and at the St. David's mine in Wales.[9] In 1903,[10] the firms of S. Neumann & Co. and Wernher, Beit & Co. purchased a quarter interest in the rights for the whole world, and prepared to push the development and application of the process. The year 1905 may be said to close the activities of the old Elmore process, as most of the plants were either closed down entirely or modified for what is now known as the Elmore vacuum process.

VAN METER AND BOSS.

James W. Van Meter and Martin P. Boss, two Americans, in 1902 invented an oil process, which was installed[11] at the Santa Barbara mine and also by the Alpimina Mining Co., both in Peru. This process was similar in its main principles to the old Elmore process, but the apparatus was somewhat different. Though the published results were good, the process has disappeared from the field of concentration in consequence of further developments, and also due to the fact that, as a result of litigation, the patents were taken over by the Elmore Company.

POTTER-DELPRAT.

Charles V. Potter, an Australian, in 1902 invented a process of mineral flotation wherein the flotation was accomplished in a 1% to 10% solution of acid. He added one ton of this solution to one ton of ore, agitated freely, and applied heat. As the temperature of the pulp increased, the heat caused the sulphides to rise to the surface, from which they were allowed to flow continuously or were skimmed off. Potter did not mention the use of any gas, but it is clear that he had in view a surface-tension process. In 1902 there had been rumours at Broken Hill[1] that a new process along radically new lines had been discovered at the Proprietary mine. This was especially interesting, as there were in the district several million tons of crushed material that had hitherto defied treatment. The rumour proved to be true, and later was announced as the Delprat or salt-cake process. The priority of patent, however, fell to Charles V. Potter, who had been working on similar lines to Guillaume D. Delprat. Potter used an acid liquor to effect flotation, while Delprat accomplished the same result in the same way with acid salt-cake solution. The effect of the acid or salt-cake is to generate bubbles of gas, which selectively adhere to the sulphides and float them. Potter and Delprat invented improvements subsequently from time to time, and their most recent patents indicate that the owners of these processes appreciate that a small quantity of oil is of decided advantage to flotation. The Potter process received its chief application at the Block 14 mine at Broken Hill, in 1905 and 1906, where it had a measure of success on sharp sand, the attempt to treat slime being attended with many difficulties; the plant is now dismantled. It was also tried at the Zinc Corporation's plant, where it was pronounced a failure. The Delprat process is installed at the Broken Hill Proprietary mine, where it is a decided success, and produces about 80,000 tons of zinc concentrate per year. This plant is the third largest flotation-concentration plant in the world, treating about 1,000 tons per day. It is a pity that a policy of secrecy as to its later developments is thought necessary. The Potter and Delprat interests soon became involved in litigation, ending in a compromise, so that the process is now generally described as the Potter-Delprat.

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[1] *Eng. & Min. Jour.*, Sept. 1, 1900, p. 241.
[2] *Eng. & Min. Jour.*, Dec. 8, 1900, p. 661.
[3] *Eng. & Min. Jour.*, June 29, 1901, p. 836.
[4] *Eng. & Min. Jour.*, July 5, 1902, p. 308.
[5] *Mineral Industry*, Vol. XI., p. 656.
[6] *Eng. & Min. Jour.*, Jan. 5, 1905, p. 160.
[7] *Mineral Industry*, Vol. XI., p. 698–707.
[8] *Eng. & Min. Jour.*, Jan. 17, 1903, p. 134.
[9] *Eng. & Min. Jour.*, Feb. 14, 1903, p. 262.
[10] *Eng. & Min. Jour.*, July 25, 1903, p. 136.
[11] *Pacific Coast Miner*, May 30, 1903, p. 391.

FROMENT.

In 1901 Alcide Froment, of Traversella, Italy, discovered that when a sulphide ore is agitated in water in the presence of a small quantity of oil and sulphuric acid, the sulphide particles become oiled and attach themselves to, and are floated by, gas bubbles. He recommended adding a small amount of calcite to ores when needed. This patent is of the greatest importance, as the successful development of oil-flotation processes has been based principally upon making use of the fact that oiled sulphide particles readily attach themselves to, and are floated by, gas bubbles. Minerals Separation Ltd. bought this patent in November, 1903. Either from a lack of financial power, or a lack of appreciation of its value, the patent was taken out only in Great Britain and Italy. Whatever the patent contains of a unique character over the Everson invention was, therefore, published in all other countries.

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[1] *Ann. Rep. Dept. of Mines*, N.S.W., 1902, p. 69.

MINERALS SEPARATION.

In 1903 a company was organized by John Ballot, J. H. Curle, W. W. Webster, S. Gregory, H. L. Sulman, and H. F. K. Picard, all of whom had for many years been interested in ore-treatment problems. The original purpose of this English company—Minerals Separation, Ltd.—was to acquire and operate the Cattermole patents. Soon after organizing, they purchased the Froment patents, and from time to time since then they have invented improvements and additions. Their present processes are based on surface-tension phenomena, accelerated by means of the addition to the pulp of very small quantities of oil and of air in a fine state of subdivision, the purpose of the oil being to adhere to the sulphides, and the purpose of the gas being to adhere to the oiled mineral particles, and to raise them to the surface in the form of a froth.

The Cattermole invention was a process of ore concentration in which use was made of the idea of oil selection. To a freely flowing pulp was added from 4% to 6% of oil in proportion to the sulphide contents and also 2% of soap, the amount depending on the metallic contents of the ore, with the object of producing granules of sulphides of a definite size, or in other words, coagulation of the sulphides. For slimy ores was added a portion of coarser sulphide particles to serve as nuclei for the formation of granules, and the separation was effected by an upcast current of water, the gangue being taken off the top and the granules at the bottom. This invention was given a thorough trial at the Central mine in Broken Hill, N.S.W., but it was a commercial failure.

Another of this company's inventions was by Sulman & Picard in 1903; a process of oil concentration in which they introduced bubbles of air or other gas, and also oil in the form of a spray, into the freely flowing acidulated pulp. This invention follows Froment and Cattermole in its main lines, but is novel in the methods of introducing the oil, and in the method of the introduction of air into the slightly oiled pulp.

The best development of this series was the introduction, in 1905, of a method which has recently been denominated by the Minerals Separation, Ltd., as the 'agitation-froth process,' a method of flotation in which an extremely small amount of oil, less than 0.1%, was added to a freely flowing pulp, followed by violent agitation for from 1 to 10 minutes. Innumerable small bubbles of air were thus mechanically included in the pulp, which joined the oil-coated mineral particles by means of the surface tension of bubbles, and floated them in the form of a froth, which was separated in a spitzkasten. The tailing from the spitzkasten was then exposed to the air as it flowed over an inclined surface, and any oiled mineral that had escaped coming in contact with air-bubbles there took up its proper air-film and floated as a film on a second spitzkasten. Other improvements in this company's method and apparatus have been made from time to time, the most important of which was the Hoover apparatus.

The only plant using the Cattermole invention was erected in Australia, on the Central mine at Broken Hill, to treat an accumulation of zinkiferous tailing from the Sulphide Corporation's lead-concentrating mill. It had a capacity of 400 tons per day, but was commercially a complete failure. This plant was then altered to use Sulman & Picard's invention and ran for two years with an average of 72 per cent. recovery of the zinc in the form of a high-grade concentrate.

The Sulphide Corporation then built a second plant, as part of a new concentrating mill, to take the current tailing from the lead concentrators, and thus has a complete mill, turning out lead concentrate by ordinary tables, and zinc concentrate by the Minerals Separation process in one continuous operation. This plant has a capacity of 900 tons per day. The Minerals Separation, Ltd., purchased the remainder of the Central mine's accumulated zinkiferous mill-tailing, and erected a third plant for the treatment of this material by their own process. This plant had a capacity of 900 tons per day. When the two last-mentioned plants were in successful operation the first plant was abandoned, being antiquated by virtue of later improvements. A fourth plant was then erected for the use of this process on an accumulation of zinkiferous and plumbiferous slime from the Block 10 and Central mines. Nearly all this material was fine enough to pass a 100-mesh screen. No difficulty was encountered in producing a pure mixed lead and zinc sulphide from this material, but the smelting of the concentrate presented such difficulty that the operation of the plant was a commercial failure. Recent developments in both the art of smelting zinkiferous concentrate and also in the methods of flotation-concentration warrant the belief that this slime-plant could now operate at a profit.

The Minerals Separation process among others was tried by the Zinc Corporation in its early struggles, but it was found to be impossible to get the results that were being obtained on the Central mine. Thereupon the Minerals Separation process was discarded in 1907 in favour of the Elmore vacuum process, which was in use for two years. Then in 1910, owing to the exhaustion of the material treatable by the Elmore vacuum process and also to decided improvements in the apparatus for the Minerals Separation process, the Elmore process was discarded and the Minerals Separation process again installed.

This process was tried in South Russia, at the Caucasus Copper mine, on a small scale, but although the trials were favourable, the company did not see fit to give it an extended application.

A unit having a capacity of 250 tons per day was installed at the Great Fitzroy mine, Queensland, and after undergoing extended trials and being several times re-modelled, it is now a partial success.

On the Orijarvi* mine, in Finland, a small unit was installed, but failed commercially.

A small Minerals Separation plant was also built at the Emu Works, Swansea, for a trial of the San Francisco del Oro ore, but the attempt was not a commercial success, because of the excessive acid consumption. Recent developments indicate that possibly this ore can be treated by flotation by the use of sodium bisulphate and other re-agents.

The Junction North mine, at Broken Hill, has installed a plant

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***Eng. & Min. Jour.*, Vol. XCI., 1911, p. 759.

designed to treat slime mixed with crushed crude ore from the mine.

A small plant was erected at the Lancefield Mine in West Australia in 1910, but it was a failure, and is now shut down.

A large plant has recently been erected on the Braden copper mine for the treatment of a copper ore which had hitherto given considerable trouble, but the troubles or others continue.

GOYDER & LAUGHTON.

Goyder & Laughton, two Australians, in 1903, invented a machine which employed Potter's idea of adding the ore to an acid solution. They were the first to disclose the principle governing Potter's and Delprat's acid-flotation processes, namely, that the action of the acid on the ore generated gas-bubbles to which the sulphide particles attached themselves and were floated to the surface. One of the difficulties of the acid-flotation process was that the bubbles broke on reaching the surface, and the mineral particles sank again, that is, the surface tension was not strong enough to hold them up under the conditions to which the particles were exposed for flotation. This invention not only seeks to obviate a bad feature of the acid-flotation process, but in a measure takes advantage of it. The machine was tried in several plants at Broken Hill, but is not now in use.

WOLF.

Jacob D. Wolf, an American, in 1903, invented a method of applying the principles of flotation. He used sulpho-chlorinated oil, or any other oil, and aimed at securing a high degree of mineral extraction with a low grade of concentrate in the first step, and, by washing the concentrate with hot water in a suitable vessel, an increase in the grade of concentrate in the second step. As another feature in his process, air or steam was blown into the tailing, wnich raised to the surface globules of lost oil, with sulphides adhering thereto, thus increasing the percentage of extraction. This patent contains several ingenious devices, and the apparatus described is new to the art. No practical application of the invention has so far been made.

ELMORE (NEW VACUUM PROCESS).

In 1904, Francis E. Elmore took out a patent for an apparatus and process wherein he secured flotation in the form of a mineral froth by the addition of a small quantity of oil, and by the liberation of the air in the pulp in a fine state of subdivision ; the liberation of the air being accomplished by subjecting the freely flowing pulp to a vacuum, and by heating, whereupon the air which is dissolved in the pulp, amounting to 2.2% in volume, at normal temperature and pressure, is released and attaches itself to the slightly oiled mineral particles, raising them to the surface. This process is performed in a machine of rather complicated design, having a capacity of 20 to 50 tons per day, depending on the nature of the ore. A battery of these is operated with comparative ease, after the men have become accustomed to the different adjustments. This process had its most noted application at Sulitelma in Norway, and also at the Zinc Corporation's plant* at Broken Hill. This last-mentioned plant had 16 units in operation, producing 75,000 tons of concentrates per year. The concentrate was re-treated by burning off the oil and then passing it over Wilfley tables to remove some of the lead. This process has been replaced by the Minerals Separation process.† The British Broken Hill Proprietary mine also had a battery of 10 vacuum machines in operation, but these have now been abandoned.

The Elmore vacuum process has also been installed at Dolcoath, Ramsley, and Dolgelly, in Great Britain,‡ at the Garpensberg, Traag, Hadeland, Sulitelma, Telemarken, and Saxberget mines in Scandinavia, and at the Edmundian mine in Africa. It has been installed, but it is not working at the present time, at the Pinnacles mine and the Cobar gold mines in New South Wales, the Namaqua copper mine in South Africa, the Caucasus copper mine in Russia, at the Avino mine in Mexico, and elsewhere.

DE BAVAY.

Auguste J. F. De Bavay, an Australian, in 1904, invented a flotation process in which a thin film of freely flowing pulp was brought to the surface of a vessel of water, where advantage was taken of the surface tension of the liquid, and the sulphide floated. He further points out that if the surface of the sulphide particles is coated with a film of carbonate from weathering, this

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**Eng. & Min. Jour.*, Vol. LXXXVIII., June 1, 1909, p. 205.

†Eng. & Min. Jour., Vol. XCI., June 1, 1911, p. 1,198.

‡Eng. & Min. Jour., Vol. LXXXIII., June 1, 1907, p. 1,037.

is detrimental to the process, and should be removed by soaking the ore in a weak solution of carbonate of ammonia, or by passing carbonic acid gas through the pulverized wet ore, or by friction.

His process was installed at the Broken Hill North mine in 1905, and was there a success. His plant and methods have undergone many changes, and he is now using a small quantity of oil and acid to enhance the extraction. He first washes the tailing free from slime, and then adds a small amount of oil to the clean sand, with agitation, and separates the scum or film of mineral sulphides in a spitzkasten. A new mill, having a capacity of 1,600 tons per day, was started in 1910 on the dumps from the Block 10 mine, combined with the current slime-free tailing of the North and South mines. This is the largest flotation-concentration plant. The venture was brought out as the Amalgamated Zinc (De Bavay's), Ltd., which corporation also owned the exclusive right to use this process at Broken Hill, the patent rights for the rest of the world being retained by the De Bavay Treatment Co. These companies have not published any comprehensible statements of cost and treatment, and little is known about the methods they use. The De Bavay patent interests have been combined with those of the Minerals Separation, Ltd., under the control of a separate company for the Australian rights. For this reason, and because the De Bavay process will treat only sharp sands, it is not likely it will have any large further commercial application.

GILLIES.

In 1906, James H. Gillies' patents were applied on a commercial scale at the Block 10 mine, Broken Hill, N.S.W. Gillies' apparatus seems to be unique; his processes were based on the principles of Potter and Delprat, but later he made use of the principles described in the Minerals Separation patents. The plant was a failure economically, and has been abandoned.

MACQUISTEN.

Arthur P. S. Macquisten, an Englishman, in 1904, invented a process and a tube apparatus therefor which made use of the surface tension of liquids for separating minerals, whereby some floated and others sank. His apparatus is new and important, but works on the old and well known principle of surface tension. In 1906 this was applied on a working scale in the

Adelaide Reduction Works, at Golconda, Nevada. The process, like all the flotation processes except the Minerals Separation and Potter-Delprat, has difficulty in handling slime.* The plant consists of 100 tubes, and the capacity is 125 tons per day. The latest development of this idea is the introduction of oil to the process, thus bringing it pretty much on a par with all the others as to the principles involved.

In 1911, the Federal Mining & Smelting Co. installed 119 of these tubes at the Morning mill at Mullen, Idaho, for the treatment of a middling product containing blende, galena, siderite, and quartz, but the results are not entirely satisfactory. The capacity is about 150 tons per day.

MUREX.

Lockwood & Samuel, in 1908, invented a process for making sulphide particles more magnetic by utilizing the selective action of oil, and in 1909 described a method of increasing the selective action of oil by treating it with various soluble salts ; also a process where magnetic or magnetizable substances are added to an ore-pulp, the whole being then treated with an oil to cause the sulphides and the magnetic particles to adhere together, whereupon they are removed from the pulp by means of a magnet. Although this is not a flotation process, it makes use of some of the principles involved, and is in some respects similar. Two units have been installed and are successfully working at Cordoba, in Spain. A plant erected at Broken Hill on the Block 14 mine has, however, had many vicissitudes ; it has been closed down as unadapted for the work, and moved recently to the Amalgamated Zinc works.

Plants have been sent to Bolivia to a mine belonging to Aramayo, Francke, & Co., and to the Malines mine in France.

ZINC CORPORATION.

This is a company organized in 1905 to work the accumulation of zinky tailing in the Broken Hill district. The company purchased, in all, more than 4,000,000 tons of tailing and slime from different mines in the district.

The company did not own any process, but the history of the company has been so closely allied to the development of this branch of the art that it is quite proper to give a brief sketch of it. The company first tried the Potter process. A plant was built in 1905 at the British Broken Hill Proprietary mine, and was intended to have a capacity of 400 tons per day. After extended trials and expensive alterations, the Potter idea was abandoned as not practical.

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* *Mineral Industry*, Vol. xv., p. 776.

In 1907 this plant was entirely re-modelled to install the Minerals Separation process. This process had been used for some time satisfactorily on the Central mine near by. The plant was designed with care, and was operated by men familiar with the process, who were employed in the adjoining Sulphide Corporation plant; but it was a complete commercial failure, and was abandoned.

Extended trials had been made in the meantime, under the management of D. P. Mitchell, with the new Elmore vacuum-concentration process. These trials had been most successful. It was decided, therefore, to move the scene of operations and build a new mill where better crushing facilities could be provided. This mill was built in 1907 and 1908 near the southern end of the Broken Hill district, and 16 Elmore units were installed. This process was a success, and ran for two years.

Then, in 1910, owing to improvements in the apparatus for the Minerals Separation process, and owing also to the depletion of supplies of material suitable to the Elmore process, the Minerals Separation process was again adopted. The Elmore units were taken out and the Minerals Separation process has now been operating on both sand and slime at a good profit for nearly four years.

The most recent step in the history of the Zinc Corporation is the amalgamation of that corporation with the Broken Hill South Blocks, Ltd., which gives the combined business, besides the excellent equipment of the Zinc Corporation and the enormous tonnage of purchased tailing, the advantage of the continuous supply of ore from the South Blocks mine.

HYDE.

In 1911 James M. Hyde, an American, invented and patented a flotation process in which a small amount of sulphuric acid, with or without the use of copperas (iron sulphate), is used to give the slimy portion of the ore a preliminary coagulation before bringing it to the flotation machine, and in which the sulphides, after agitation, are floated off rapidly and as completely as possible, with a considerable overflow of freely-flowing water, thereby producing an impure concentrate which is re-treated in a second machine, from which only high-grade concentrate is taken off, with no freely-flowing water. The process has been adopted by the Butte & Superior Copper Company of Butte, Montana, in their new 500-ton zinc mill, which is shortly to be increased to a capacity of 1,000 tons per day. The process is giving highly satisfactory results. This is the first attempt to use a flotation process on a large scale in the United States.

Many other inventions have been made, and the patents will be summarized in the next chapter. The foregoing ones are those which it is deemed necessary to mention here for reason of their technical importance.

The recent amalgamation of the patent interests of the Amalgamated Zinc, Ltd., and the Minerals Separation, Ltd., in Australia, is a step in the right direction, as it will stop litigation already begun, and prevent more that was threatened. The De Bavay patent rights for the rest of the world are now owned by Minerals Separation, Ltd. The patents now included under the one group are those of Froment, Potter, Delprat, Cattermole, Sulman, Picard, Ballot, De Bavay, Goyder, Laughton, Higgins, Greenway, Chapman, Lavers, Nutter, Hoover, Hebbard and Lyster.

A much clearer idea of the evolution of the processes can be secured from a summary of the patents in chronological order, which is given in the next chapter. Some repetition will be necessary, but the history of metallurgical devices is largely a recital of alterations and experiments.

CHAPTER II.

PATENTS.

In this analysis the intention is to set forth the flotation patents as they appeared from time to time, from 1860 to 1912, and to paraphrase and explain the meaning of them in language somewhat simpler than the legal phraseology of the patent. As the development of these processes has taken place mainly in Great Britain and the Colonies, the records of the English Patent Office have been followed as to dates, although those of the United States and of other countries present some exception to strict chronology.

A careful search of the records of the patent offices of Great Britain and the United States reveals nothing prior to the year 1860 that in any way bears upon the subject of concentration by flotation.

EXPIRED PATENTS.

WILLIAM HAYNES, in British patent No. 488, February 23, 1860, described a process for separating mineral sulphides from the gangue or rocky constituent of an ore by the use of oily, gummy, or bituminous matter. This was not a flotation process, but must be considered the pioneer movement in that direction. The process described in the patent is as follows:

1. The ore is ground to the requisite fineness.
2. An agent, which may be a fat or an oil, alone or in combination with other things, is added to the crushed ore in the proportion of one part of agent to five or nine of ore.
3. The agent and the ore are mixed or agitated in a proper machine.
4. Sufficient water, preferably warm, to cover the whole is added to the agitated and mixed mass.
5. The water and the mixed mass of ore and agent are passed through a proper triturating machine, by which operation the combined sulphides and agent alone remain in union, while the earthy matter or gangue of the ore sinks to the bottom of the water.

The central idea of this invention is the separation in a triturating machine of sulphides from gangue by means of the selective adhesion of oils for sulphides.

John Tunbridge, in United States patent No. 228,004, Nov. 4, 1879, described a process for recovering finely comminuted metal held in suspension in water by the use of soap or a saponaceous compound. This patent is just nearly enough related to the subject matter of this discussion to be mentioned for the sake of completeness.

Hezekiah Bradford, in United States patent No. 345,951, June 22, 1885, described a process for separating sulphides from gangue by what is clearly the first well defined surface-tension flotation process.

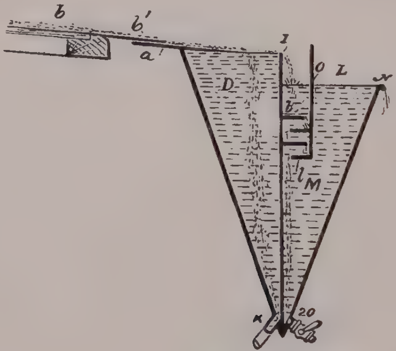

Fig. 1.—Bradford Apparatus.

For the treatment of wet tailing from tables, vanners, and jigs, one method is described, but for the treatment of dry crushed ore it is specified that the dry ore is to be sprinkled on the surface of water with as little concussion as possible, and from this point the treatment is obviously the same as with wet tailing.

In its simplest form the apparatus prescribed takes the tailing, mixed with water from some previous operation, at a point, say *b* (Fig. 1), which may be a moving portion of a shaking table. By means of an adjustable lip *b'*, the pulp is transferred to an inclined plane *a*, in passing over which the sulphide particles become exposed to the air, and the force of the surface tension of the liquid acting on these sulphide particles causes them to float on the surface of the liquid in the receptacle *D*, while the gangue, which remains wetted throughout the operation, sinks in receptacle *D*, and is removed at *K*. The sulphides, on the other hand, which are floating at the surface of receptacle *D*, float across the receptacle to the lip *I*, and plunge into the liquid contained in receptacle *L*. The baffles *l* arrest the fall of the sulphides and assist them to become wetted, so that the force of surface tension no longer acts on them, and they sink quietly to the bottom of receptacle *M* and are removed at 20, while the superfluous water passes over the lip *N*.

The central idea of this invention is the separation of sulphides from gangue by flotation of the sulphides at the surface of a freely flowing ore-pulp, through the action of the force of surface tension of the liquid.

CARRIE J. EVERSON, in United States patent No. 348,157, Aug. 29, 1885, described a process for separating the sulphides in an ore from the gangue. The patent describes two distinct processes, the first of which is analogous to that of Haynes. The main improvement made by this first Everson process over that of Haynes is the discovery that acids increase the selective adhesion of oils for sulphide particles.

The second method which Everson described is a flotation process pure and simple, and is of interest :—

(1). The oil should desirably be first mixed with the ore.

(2). Water containing a suitable amount of free acid in quantity ample for the operation to follow, is added to the mixed ore and oil.

(3). Thorough agitation of the mass.

(4). Removal of the concentrate by flotation and a constant overflow of water from the washing-out vessel.

(5). The gangue being heavier, the inventor says, than the mixed oil and sulphides, sinks to the bottom of the washing-out vessel and can be removed there.

The central idea of this invention is the separation of sulphides from gangue by flotation of the sulphides at the surface of the liquid in a vessel, this flotation being accomplished through the agency of the forces brought to bear on the ore-pulp by the addition of oil and acid, and by thorough agitation.

EDWARD DODÉ, in British patent No. 14,357, Sept. 11, 1889, described a process that refers to the separation of metallic gold, silver, etc., from other metals by first dissolving them in acid solution and then treating them with oily substances.

HEBRON & EVERSON, in United States patent No. 471,174, September 1, 1891, described a process wherein they mixed a 'buoy-stock'* with the ore. This process is in the main similar to Everson's, and has some remarkable affinities with Bradford's, but there is some radical departure from previous patents.

The essential feature of the invention consists in submitting the ore and the buoy-stock to a rubbing movement, so that the particles of buoyant material are pressed into the cavities and pores of the mineral and made to adhere to the rough and irregular surfaces thereof, so that the joined mineral and buoyant material are of less specific gravity than the rock particles of the ore.

Charles B. Hebron, in United States patent No. 474,829, July 22, 1891, describes an improvement to the Hebron & Everson invention, which consists in subjecting the mixed ore and 'buoy-stock' to a vacuum and heat, thus greatly increasing the efficiency of the 'buoy-stock.' This patent is built upon the foregoing one, but emphasizes two important points:

(1). The buoyant material is more advantageously added to the ore hot, in a vacuum, as in that case the buoyant material comes into closer union and is more intimately joined to the metallic or sulphide particles.

(2). After the buoyant material has been mixed with the ore in a vacuum, the ore must be thoroughly aerated by blowing air through the mass.

The prepared ore was then submitted to a flotation treatment, substantially the same as that described in Hebron & Everson, where the addition of air to the operation and effervescence of the liquid are recommended.

Edgar A. Hockley, in United States patent No. 466,753, Jan. 5, 1892, described an invention whereby particles of metal or mineral may be recovered by flotation aided by the introduction of air.

Albion M. Rouse, in United States patent No. 469,599, Feb. 23, 1892, described a method of creating a froth or foam of matter foreign to water, and the recovery thereof.

Maleczek, in New South Wales patent No. 3823, of the year 1892, described a frothing process, wherein, as a result of treating the ore with salt solution in hot oil, the sulphides were floated to the surface as a froth, presumably through the agency of air or other bubbles.

Joseph William Sutton, in British patent No. 24,144, Dec.

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* This word occurs in the patent, but needs no further explanation than that the material was composed largely of grease.

31, 1892, described a process for recovering gold from its solution by means of flotation with oils in an acidified liquor. This patent is just nearly enough related to the subject matter of this discussion to be mentioned for the sake of completeness.

Joseph William Sutton, in United States patent No. 521,899, Dec. 28, 1892, duplicated his British patent No. 24,144, Dec. 31, 1892.

Henry Livingstone Sulman, in British patent No. 24,939, Dec. 28, 1893, described a process for preventing the loss of 'float' gold in milling operations, by adding certain substances that cause it to sink by diminishing the surface-tension of the liquid. This patent is just nearly enough related to the subject matter of this discussion to be mentioned for the sake of completeness.

Robson & Crowder, in British patent No. 427, Jan. 8, 1894, described a process for separating sulphides from gangue. This invention made use of the idea that oils have a selective adhesion for sulphides, but it differs from the previous inventions in that no acid nor air was used in the operation.

(1). The crushed ore, if not already in a proper state, was first moistened with water.

(2). The moistened ore was then mixed with a large volume of oil, with constant stirring and the continuous addition of oil.

(3). The sulphide particles were thereby floated away over the lip of the vessel by the constant overflow of oil.

This process does not seem to be much of an advance in the art. There have been some recent patents of a similar kind describing processes for separating mixed sulphides, but they are of doubtful utility. As this patent departs from the progressive line of development indicated by previous patents, and also because the line it takes has come to no commercial application, it is not necessary to consider it further, but it is here mentioned for the sake of completeness.

John Henry McCoy, in United States patent No. 577,825, Feb. 11, 1895, described an invention for introducing air into a pointed box, for the purpose of separating particles. This is not a flotation process, but is mentioned for the sake of completeness.

UNEXPIRED PATENTS.

Francis Edward Elmore, in British patent No. 21,948, Oct. 18, 1898, described a flotation process that involved the idea of oil-selection and the idea of oil-buoyancy flotation. He mixed the ore with several times its weight of water, and an equal or several times greater weight of oil, in a revolving drum, so constructed and operated as to give a mixing effect without breaking up or emulsifying the oil, which was added with the ore. After thus gently mixing, the mass was allowed to run into a spitzkasten, where the oil carried the sulphides to the surface, and the gangue and the water were removed from the bottom. This patent marks a decided advancement in flotation-concentration; it was the first process of the kind to approach commercial success.

Francis Edward Elmore, in United States patent No. 653,340, April 10, 1899, duplicated in the main his apparatus in the British patent just described.

Francis Edward Elmore, in United States patent No. 676,679, April 10, 1899, duplicated his process described in British patent No. 21,948, Oct. 18, 1898.

Alexander Stanley Elmore, in British patent No. 6,519, Mar. 28, 1901, described a method of increasing the selective action of oil by adding acid to the pulp.

Alexander Stanley Elmore, in United States patent No. 689,070, April 13, 1901, duplicated the process described in British patent No. 6,519, Mar. 28, 1901.

Edmund L. Van Der Naillen, in United States patent No. 737,533, June 20, 1901, described an apparatus for ore concentration having a horizontal section decreasing in area upward. This patent is of limited interest.

John Klein, in United States patent No. 696,739, July 12, 1901, described a machine to which air was introduced for the purpose of carrying a portion of the ore off the top of the liquid and allowing the balance to sink. This is a patent of limited interest in this discussion.

Alexander Stanley Elmore, in British patent No. 15,526, July 31, 1901, described two forms of apparatus for conducting the processes previously patented by Francis E. Elmore. One form was designed to effect the separation of sulphides from the gangue by oil-buoyancy flotation, and differs little in principle from the apparatus described by Francis E. Elmore in his original patent. The other form of apparatus described is intended to effect the separation by a sort of oil-amalgamation, in which the oiled pulp flowed under and in contact with an oiled or greased canvas belt, which carried the oil and oiled mineral out of the pulp. This patent is of interest in that the latter process therein described is extensively used at Kimberley, in South Africa, to separate diamonds from the 'blue ground.'

ALEXANDER STANLEY ELMORE, in United States patent No. 692,643, Aug. 8, 1901, duplicated the apparatus described in British patent No. 6,519, Mar. 28, 1901.

ALEXANDER STANLEY ELMORE, in United States patent No. 703,905, Aug. 8, 1901, duplicated British patent No. 15,526, July 31, 1901.

CHARLES VINCENT POTTER, in United States patent No. 776,145, Jan. 14, 1902, duplicated his British patent No. 1,146, Jan. 15, 1902.

CHARLES VINCENT POTTER, in British patent No. 1,146, Jan. 15, 1902, described a process of mineral flotation wherein the flotation was accomplished in a 1% to 10% acid solution. He added one ton of this solution to one ton of ore, agitated freely, and applied heat. As the temperature of the pulp increased, the heat caused, he says, the sulphides to rise to the surface, from which they were allowed to flow continuously or were skimmed. This patent deserves honourable mention, as it led to the recent decided development in flotation methods. Potter did not mention the use of any gas, but it is clear that he had in view a gas-bubble process.

HAULTAIN & STOVEL, in British patent No. 9,521, April 24, 1902, described a machine of the familiar Frue-vanner type, in which the concentrating belt was made of canvas, and was coated with a layer of thick oil. They thus took advantage of the well known specific gravity separation, and combined with it the principles of oil-selection. They separated the concentrate from the oil in hot water, when the oil, becoming fluid, rose to the surface, and the sulphides remained at the bottom.

CHARLES W. MERRILL, in United States patent No. 728,487, May 12, 1902, described a concentrating apparatus with a horizontal section decreasing upward. This patent is of just sufficient interest to be mentioned for the sake of completeness.

ALCIDE FROMENT, in British patent No. 12,778, June 4, 1902, described a flotation process that involved the use of oil, and also of a gas. He recognized clearly the important principle, which is emphasized in later developments, that when ore, water, oil, acid, and a gas are mixed and agitated together in the proper proportions, the oil not only has a selective action for the sulphides, but the gas also has a selective action for the oiled particles, and it is not necessary to have a large amount of oil present to float the sulphides by oil-buoyancy. He mixed the ore with three times its weight of water, and added a small quantity of oil. If there was no gas-forming mineral in the ore, a little limestone was added, and then also a small quantity of acid, which generated carbon dioxide in the pulp. He then agitated freely. He says that the oiled mineral particles collected in spherules and were carried to the surface by the gas bubbles. Finally, he enunciates this important principle: 'The rapidity of the formation of the spherules and their ascension is in direct ratio to the quantity of gas produced in the pulp in a given time.' This patent was taken out only in Great Britain and Italy.

JOSEPH BARTON SCAMMELL, in British patent No. 15,280, July 9, 1902, described a method of thickening oils by the addition of sulphur chloride, in order to increase the buoyancy of the oil and so increase the efficiency of the oil-buoyancy flotation processes. He agitated the ore, water, and sulpho-chlorinated oil in a suitable vessel, transferred the mass to settling-pans, and after a time skimmed the oil with the sulphides.

GUILLAUME DANIEL DELPRAT, in British patent No. 26,279, Nov. 28, 1902, described a process of flotation that consisted in immersing the ore in a hot, but not boiling, solution (of specific gravity 1.4) of salt-cake, or a solution (of specific gravity 1.4) of sodium sulphate and sulphuric acid. The ratio of sodium sulphate to sulphuric acid was 2.5 : 1. The sulphides in the ore, he says, floated at the surface and were removed by a stream of water or by skimming.

ARTHUR EDWARD CATTERMOLE, in British patent No. 26,295, Nov. 28, 1902, described a process of oil-concentration in which he made use of the idea of oil-selection. His method of procedure is not made plain in his patent, but seems to be about as follows: To a freely flowing pulp he added from 4% to 6% of oil, and 2% of soap, the amount depending on the metallic contents of the ore, his object being to produce granules of sulphides of a certain size. For slimy ores he added a portion of coarser sulphide particles to serve as nuclei for the formation of granules, and effected the separation by an upcast current of water, taking the gangue off the top, and the granules at the bottom. For ores containing small amounts of mineral he added a portion of oiled pumice or oiled charcoal to serve as nuclei, and removed the granules so made by flotation. After the concentrate had been secured, the oil was recovered by treating the oiled sulphides with an alkali, thus dissolving the oil and making it available for use again.

Arthur Edward Cattermole, in British patent No. 26,296, Nov. 28, 1902, described a process of classifying mixed sulphides after they had been removed from an ore by his oil-granules concentration process. He accomplished this classification of sulphides by fractionally dissolving the oil of the granules in alkaline emulsifying agents of varying strength and activity. He first added to the oiled concentrate, with agitation, an alkaline solution that had a strength just sufficient to dissolve the oil from the sulphides having the least adhesiveness for the oil. This sulphide of least adhesiveness for oil was freed from the mixed sulphide granules, and was removed by an upcast of water or other suitable device. An alkaline solution of greater strength was then added to the remaining portion, with agitation, and the oil was dissolved from the sulphide having the next second adhesiveness for oil. This second sulphide was released in the same way as the first; and so the process was repeated as often as was necessary.

Guillaume Daniel Delprat, in United States patent No. 735,071, Jan. 2, 1903, described a process whereby flotation of sulphides is secured in a nitric acid solution.

Guillaume Daniel Delprat, in United States patent No. 768,035, Jan. 2, 1903, duplicated British patent No. 26,279, Nov. 28, 1902.

Alexander Stanley Elmore, in British patent No. 184, Jan. 3, 1903, described an improved apparatus for oil-concentration wherein air was excluded from the operation. His method was substantially the same as that described in his previous patent, and that of Francis E. Elmore, except that by sealing all open vessels with a ring or surface of oil, the operation was performed in such a manner as to prevent the introduction of air into the pulp, and thus prevent the possibility of oxidation of the minerals. He also describes two methods of removing the concentrate from the oil, one by heat and one by filter-press treatment. He calls attention to the necessity of cooling the oil after heating, presumably for the purpose of maintaining its viscosity and to prevent emulsification.

Joseph Barton Scammell, in United States patent No. 770,659 Jan. 31, 1903, duplicated his British patent No. 15,280, July 9, 1902.

Guillaume Daniel Delprat, in United States patent No. 763,662, Mar. 9, 1903, described a new form of apparatus for the application of his processes described in United States patents Nos. 735,071 and 768,035, Jan. 2, 1903.

Henry A. Allen, in United States patent No. 762,870, Mar. 16, 1903, described a complicated apparatus for treating ores with oil and other chemicals under super-atmospheric pressure.

Jacob David Wolf, in United States patent No. 787,814, May 22, 1903, duplicated British patent No. 4,793, May 22, 1903.

Jacob David Wolf, in British patent No. 4,793, May 22, 1903, described a method of applying the principles of oil flotation. He used sulpho-chlorinated oil, with violent agitation in a mixer like Fig. 2, and aimed at securing a high degree of mineral extraction with a low grade of concentrate in the first step, and by washing the concentrate with hot water in a suitable vessel at increasing the grade of concentrate in the second step; as a third step in his process, air or steam was blown into the refuse, which raised to the surface globules of lost oil, with some sulphides adhering thereto, thus increasing the extraction.

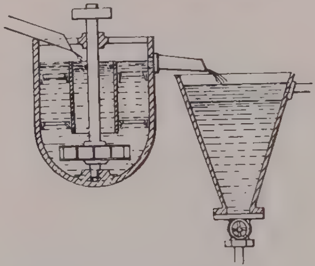

Fig. 2.—Wolf Apparatus.

Cosmo Kendall, in United States patent No. 771,075, July 21, 1903, described a process of separating graphite from gangue by means of oil.

Goyder & Laughton, in British patent No. 16,839, July 31, 1903, described a process of ore concentration that employed the idea of adding the ore to an acid solution. They describe an apparatus for trapping the mineral sulphides as they are brought to the surface. They were the first to disclose the principle governing Potter's and Delprat's acid-flotation processes, namely, that the action of the acid on the ore generated gas-bubbles, to which the sulphide particles attached themselves and were floated to the surface. One of the difficulties of the acid-flotation process was that the bubbles broke on reaching the surface, and the mineral particles sank again, that is, the surface tension was not active enough to hold them up. This invention not only seeks to obviate this bad feature of the acid-flotation process, but in a measure takes advantage of it. This machine has horizontal sections decreasing in area upward.

Goyder & Laughton, in United States patents No. 763,749 and 784,999, Aug. 5, 1903, described an improved form of apparatus and process for the application of the acid-flotation process of Potter, being a duplicate of British patent No. 16,839, July 31, 1903.

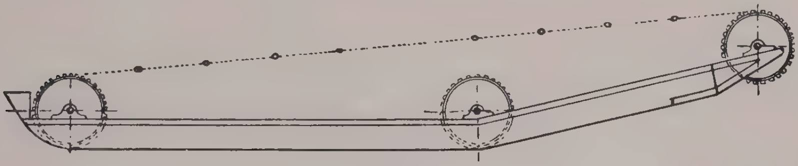

Fig. 3.

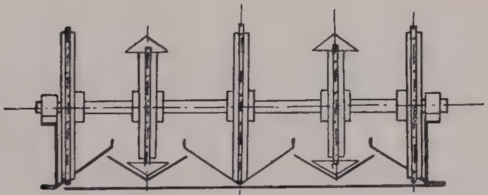

Fig. 4.—Goyder and Laughton Apparatus.

Cattermole, Sulman & Picard, in British patent No. 17,109, Aug. 6, 1903, described a process of concentration that consisted in (1) mixing the freely flowing pulp with a soap solution and agitating; (2) adding a small portion of acid to liberate the fatty acid from the soap, whereby the sulphides collected in granules, as disclosed previously by Cattermole, and were removed from the pulp by an upcast current of water; and (3) generating a gas in the pulp to remove the granules by flotation. After the concentrate was removed, it was treated with an alkali, which dissolved the oil of the granules, converting it into a soluble soap, which was immediately available for use again.

Moritz F. R. Glogner, in United States patent No. 736,381, Aug. 18, 1903, described a process for the recovery of graphite by means of an oil and froth process.

Jacob David Wolf, in New South Wales patent No. 13,571, Aug. 19, 1903, duplicated his British patent No. 4,793 of May 22, 1903.

Van Meter & Boss, in United States patent No. 762,774, Aug. 19, 1903, described an apparatus for the application of the oil-buoyancy process.

Alfred Schwarz, in United States patent No. 766,289, Aug. 19, 1903, described a process for separating sulphides from gangue by the use of oil and saline solutions, or other liquids differing in specific gravity. His apparatus is different from any previously described, and he gives a theory for his process which it is difficult to accept.

Arthur Edward Cattermole, in British patent No. 18,589, Aug. 28, 1903, secured a revision and amplification of his previous patents, and described the formation of granules. He describes an improved form of apparatus. This process failed of practical application.

Homer L. Orr, in United States patent No. 758,464, Sept. 1, 1903, described an apparatus for separating metallic particles in an ore by means of oil and other chemicals.

Guillaume Daniel Delprat, in British patent No. 19,783, Sept. 14, 1903, described a flotation process wherein the bisulphate of an alkali metal is used.

Sulman & Picard, in British patent No. 20,419, Sept. 22, 1903, described a process of oil-concentration in which they introduced bubbles of air or other gas, and also oil in the form of a spray, into the freely flowing acidulated pulp. This invention follows some of their previous patents in its main lines, but is novel in the methods of introducing the oil and air into the slightly oiled pulp.

Sulman & Picard, in New South Wales patent No. 13,632, Sept. 24, 1903, described a process consisting in the recovery of metallic particles in an ore by floating them to the surface with bubbles and films of air, after oiling them with a small amount of oil in an acid circuit.

Arthur Edward Cattermole, in United States patent No. 763,260, Sept. 28, 1903, duplicated British patent No. 26,295, Nov. 28, 1902.

Arthur Edward Cattermole, in United States patent No. 777,273, Sept. 28, 1903, duplicated British patent No. 18,589, Aug. 28, 1903.

Arthur Edward Cattermole, in United States patent No. 763,259, Sept. 29, 1903, duplicated British patent No. 26,296, Nov. 2, 1902.

Sulman & Picard, in United States patent No. 793,808, Oct. 5, 1903, duplicated British patent No. 20,419, Sept. 22, 1903.

Alice H. Schwarz, in United States patent No. 771,277, Nov. 6, 1903, described a process of ore concentration in which she made use of an oil or grease that is solid at ordinary temperatures.

Israel F. Good, in United States patent No. 745,960, Dec. 1, 1903, described an oil-flotation method of recovering graphite from rock.

Guillaume Daniel Delprat, in British patent No. 27,132, Dec. 11, 1903, described the use of a solution of common salt and sulphuric acid to be used in the acid-flotation processes previously described by him.

Alexander Stanley Elmore, in United States patent No. 865,334, Dec. 11, 1903, duplicated British patent No. 184, Jan. 3, 1903.

Edmund B. Kirby, in United States patent No. 809,959, Dec. 14, 1903, described a process of oil-and-gas flotation, in which air was blown into the previously agitated oiled pulp.

Cattermole, Sulman & Picard, in United States patent No. 788,247, Mar. 29, 1904, duplicated British patent No. 17,019, August 6, 1903, in part.

Cattermole, Sulman, & Picard, in United States patent No. 777,274, Mar. 29, 1904, duplicated in part British patent No. 17,109.

James D. Darling, in United States patent No 763,859, April 28, 1904, described a method of separating carbon from impurities by means of oil.

Sulman & Picard, in British patent No. 13,481, June 14, 1904, described a method of slime-deposition by means of soap, which produces coagulation. This is of limited interest to this discussion.

Francis Edward Elmore, in British patent No. 13,578, June 15, 1904, described a process of flotation wherein he made use of the electrolysis of water to generate gas in a freely flowing pulp. This patent is chiefly of interest in that it marks the departure of this inventor from his old line of oil-buoyancy flotation, emphasized in his former patents; he thenceforth turns his attention to gas-and-oil flotation.

Jacob David Wolf, in British patent No. 17,407, Aug. 10, 1904, described an apparatus similar to that of Haultain & Stovel.

Francis Edward Elmore, in British patent No. 17,816, Aug. 16, 1904, described a process to be performed in a vacuum or a partial vacuum. He says that he uses a small quantity of oil, and that "under a vacuum or partial vacuum, air or gases dissolved in the milling water are liberated. These liberated gases may be augmented by the generation of gases in the pulp, or by introduction from an external source." The apparatus is an admirable invention, and the patent discloses a new principle, namely, the use of the vacuum in connection with the flotation.

Auguste Joseph Francois De Bavay, in British patent No. 18,660, Aug. 29, 1904, described a flotation process in which a thin film of freely flowing pulp was brought on to the surface of a vessel of water, where advantage was taken of the surface tension of the liquid, and the sulphide floated. He further points out that, if the surface of the sulphide particles is coated with a film of carbonate from weathering, this is detrimental to the process, and should be removed by (1) soaking the ore in a weak solution of carbonate of ammonia, or (2) passing carbonic gas through the pulverised wet ore, or (3) by friction.

James Hyndes Gillies, in United States patent No. 778,747, Sept. 7, 1904, duplicated British patent No. 20,159, Sept. 19, 1904.

James Hyndes Gillies, in United States patent No. 780,281, Sept. 8, 1904, duplicated British patent No. 20,160, Sept. 19, 1904.

James Hyndes Gillies, in British patent No. 20,159 and No. 20,160, Sept. 19, 1904, described an apparatus to be used in conducting the Potter and Delprat processes.

Sulman & Picard, in Commonwealth patent No. 1,909, Oct. 27, 1904, duplicated their N.S.W. patent, No. 13,632.

Alfred Schwarz, in British patent No. 23,906, Nov. 4, 1904, described a process of concentration wherein he added to a dry or slightly wet pulp a portion of fat, oil, or resinous substance, which was solid at ordinary temperature. After several complicated manipulations, the oil and mineral were separated from the gangue by flotation. This is a duplicate of United States patent No. 771,277, Nov. 6, 1903, by Alice H. Schwarz.

Arthur Penrhyn Stanley Macquisten, in British patents No. 25,204 and No. 25,204 A, Nov. 19, 1904, described a process and apparatus therefor, making use of the surface tension of liquids for separating minerals, whereby some floated and others sank. His apparatus is new and important, but works on the old and well known principle of surface tension.

Auguste Joseph Francois De Bavay, in British patent No. 25,858, Nov. 28, 1904, described an apparatus for mineral separation by the process described in his patent of Aug. 29, 1904, previously mentioned.

Auguste Joseph Francois De Bavay, in United States patent No. 864,597, Dec. 19, 1904, duplicated British patent No. 18,660, Aug. 29, 1904.

Auguste Joseph Francois De Bavay, in United States patent No. 912,783, Dec. 19, 1904, described an apparatus for performing processes at pressures above normal.

Sulman, Picard, & Ballot, in British patent No. 29,374, Dec. 31, 1904, described a process and apparatus therefor wherein they made use of the idea of oil-and-gas flotation combined with surface tension. A mineral particle coated with a film of oil not only adheres to a small bubble of air or other gas introduced into the pulp, and floats with the bubble, but all oiled particles that are exposed to the air above the surface of the pulp take unto themselves films of air of much larger dimensions than if un-oiled, and so float more readily than un-oiled particles.

Francis Edward Elmore, in British patent No. 29,282, Dec. 31, 1904, described an apparatus to perform the operation described in his vacuum-process patent.

Sulman & Picard, in British patent No. 1,821, Jan. 30, 1905, described a process that depends on the surface tension of the liquid.

Sulman, Picard, & Ballot, in United States patent No. 879,985, Feb. 2, 1905, duplicated British patent No. 29,374, Dec. 31, 1904.

Walter Murray Sanders, in United States patent No. 805,382, Feb. 7, 1905, described a method of gas-flotation in which he used alkaline solutions to generate bubbles of hydrogen gas on the minerals.

Sulman, Picard, & Ballot, in British patent No. 5,260, Mar. 13, 1905, described a process of flotation in which they revert to surface tension as applied to dry ores. In the simplest method described by them they sprinkle the dry ore on the surface of the liquid in a spitzkasten. The sulphides being more difficult to wet, or rather, adhering more strongly to their air-films than the gangue, float, and the gangue sinks.

ALEXANDER STANLEY ELMORE, in British patent No. 5,953, Mar. 21, 1905, described a method of using calcium chloride and other chlorides in flotation-concentration.

SULMAN, PICARD, & BALLOT, in British patent No. 7,803, April 12, 1905, described a process of flotation in which they added extremely small amounts of oil, less than 0.1%, to a freely flowing pulp, and gave it violent agitation for from 1 to 10 minutes.

CYRIL DOUGLAS McCOURT, in British patent No. 10,475, May 18, 1905, described a process for concentrating graphite and other non-metallic substances by means of oil-flotation. No new principle is disclosed herein, but previously patented processes are put to a new use.

SULMAN, PICARD, & BALLOT, in United States patent No. 835,120, May 29, 1905, duplicated British patent No. 7,803, April 12, 1905.

SULMAN, PICARD, & BALLOT, in United States patent No. 835,479, May 29, 1905, duplicated British patent No. 26,712, Dec. 21, 1905.

HENRY LIVINGSTONE SULMAN, in Commonwealth patent No. 4,667, June 6, 1905, duplicated his invention in British patent No. 19,709, Sept. 25, 1905.

ARTHUR PENRHYN STANLEY MACQUISTEN, in United States patent No. 865,194, July 3, 1905, duplicated British patent No. 25,204, Nov. 19, 1904.

FRANCIS EDWARD ELMORE, in United States patent No. 826,411, July 10, 1905, duplicated his process in British patent No. 17,816, Aug. 16, 1904.

ALFRED SCHWARZ, in United States patent No. 825,080, July 12, 1905, described an improved form of apparatus for use in his processes previously described.

ALFRED SCHWARZ, in United States patent No. 842,255, July 19, 1905, duplicated British patent No. 23,906, Nov. 4, 1904.

ARTHUR PENRHYN STANLEY MACQUISTEN, in British patent No. 15,119, July 22, 1905, described an improvement to his surface-tension process, in which he made use of oil and various salts and acids.

HENRY LIVINGSTONE SULMAN, in British patent No. 19,709, Sept. 29, 1905, described an improvement upon the previous oil-and-gas process; this consisted in bringing the contents of the agitating-vessel to a boiling temperature.

Jacob David Wolf, in British patent No. 20,322, Oct. 7, 1905, described an improvement to his greased-belt apparatus.

Henry Livingstone Sulman, in United States patent No. 835,143, Oct. 20, 1905, duplicated British patent No. 19,709, Sept. 29, 1905.

Sulman, Picard, & Ballot, in British patent No. 26,711, Dec. 21, 1905, described a process for separating heavy sulphides from each other. They begin with the known fact that in a pulp containing mixed sulphides in a sunken condition, if the sulphides are raised above the surface and allowed to drain, the sulphides take unto themselves films of air, and upon again seeking to immerse the drained pulp, the sulphides float; and they discovered also that the time required for drainage and taking on of air-films varied in the different sulphides. By taking advantage of these drainage periods of different lengths they could effect a separation of the sulphides from each other. This is a novel conception, but the practical application of it has been a failure.

Sulman, Picard, & Ballot, in British patent No. 26,712, Dec. 21, 1905, described a method of applying oil-and-gas flotation. This consisted in subjecting a freely flowing oiled pulp to pressure, for the purpose of dissolving air or other gas therein, and when the pressure on the pulp was removed, the air immediately escaped from solution and collected the oiled minerals and floated them; highly aerated water being also introduced with the pulp for the same purpose. They make use herein of facts well known in physics under the name of Henry and Dalton's law, namely, the quantity of gas dissolved in water is in direct proportion to the pressure.

Sulman, Picard, & Ballot, in Commonwealth patent No. 5,150, Jan. 31, 1906, duplicated British patent No. 26,712, 1905.

Sulman, Picard, & Ballot, in Commonwealth patent No. 5,334, Feb. 26, 1906, duplicated British patent No. 26,711, 1905.

Arthur Penrhyn Stanley Macquisten, in United States patent No. 865,195, Mar. 17, 1906, duplicated British patent No. 25,204a, Nov. 19, 1904.

James Francis Latimer, in United States patent No. 851,600, Mar. 27, 1906, described flotation processes as applied to graphite concentration.

Sulman & Sulman, in British patent No. 9,981, April 28, 1906, described the adaptation of the buddle and rubber strakes to flotation processes, whereby the particles are exposed to the air advantageously.

Auguste Joseph Francois De Bavay, in Commonwealth patent No. 6,239, June 21, 1906, described a flotation process where a fluoride or a carbonate is added to the acid pulp.

George Albert Chapman, in British patent No. 17,328, Aug. 1, 1906, described an improvement to Sulman's previous patents. This is a method of limiting the amount of acid used in flotation. While it is advantageous to have some acid in the pulp to increase the selective action of the oil, it is not necessary to maintain the acidity of the whole mass for more than a short time; the operation can be carried on in a neutral circuit if the acid is added before the oil. This is a working detail of considerable importance.

Henry Livingstone Sulman, in British patent No. 19,944, Sept. 7, 1906, described a process in which the separation of minerals was brought about by the repeated exposure of the particles to the air, and by warming the liquid in which the operation was performed.

Walter Murray Sanders. in United States patent No. 988,737, Oct. 27, 1906, patented a non-acid process of flotation-concentration.

Dudley Hiram Norris, in United States patent No. 864,856, Nov. 19, 1906, described a method of effecting a separation of minerals by flotation by adding to a freely flowing pulp a portion of water in which air was dissolved at high pressure. His apparatus is new.

Walter Murray Sanders, in United States patent No. 911,077, Mar. 27, 1907, described an apparatus for performing flotation processes.

Hoover & Sulman, in British patent No. 13,268, June 7, 1907, described an apparatus for performing the high-pressure operation previously described by Sulman, Picard, & Ballot.

Dudley Hiram Norris, in amended British patent No. 14,806, June 27, 1907, duplicated his United States patent No. 864,856, 1906, with modifications.

Marcus Ruthenburg, in British patent No. 28,191, Dec 21, 1907, described a method of separating mixed sulphides by using a light oil instead of water, in ordinary table or vanner concentration.

Lockwood & Samuel, in British patent No. 12,962, June 17, 1908, patented a process for making sulphide particles more magnetic by utilizing the selective action of oil.

FRANK BURNETT DICK, in British patent No. 16,667, Aug. 7, 1908, described a process for treating copper ores by an oil-and-gas flotation process, where the ore is given a preliminary preparation by a reducing roast.

LOCKWOOD & SAMUEL, in British patent No. 26,264, Dec. 4, 1908, described a method of increasing the selective action of oil by treating it with various salts.

ARTHUR HOWARD HIGGINS, in British patent No. 26,852, Dec. 10, 1908, described a flotation process in which the frothing agents are aromatic hydroxides such as phenol.

SULMAN, PICARD, & BALLOT, in British patent No. 28,173, Dec. 24, 1908, described a method of securing flotation by the use of soluble frothing agents of the alcohol series.

HENRY AZOR WENTWORTH, in United States patent No. 938,732, Jan. 2, 1909, described a process of separating sulphides from each other where the sulphides were submitted to a slight roast for the purpose of rendering one or more of the sulphides non-floatable.

LOCKWOOD & SAMUEL, in British patent No. 16,229, Jan. 7, 1909, described a process wherein magnetic or magnetizable substances are added to an ore-pulp, the whole then treated with an oil to cause the sulphides and the magnetic particles to adhere together, when they are removed from the pulp in a magnetic machine.

LOCKWOOD & SAMUEL, in United States patent No. 933,717, Jan. 11, 1909, duplicate in part British patent No. 12,962, June 17, 1908.

EDWARD JAMES HORWOOD, in Commonwealth patent No. 12,763, Jan. 13, 1909, described a process for separating zinc sulphide from lead sulphide by flotation, after first giving the concentrate a slight roast.

EDWARD JAMES HORWOOD, in amended British patent No. 1,789, Jan, 25, 1909, duplicated his Commonwealth patent No. 12,763, Jan. 13, 1909.

GREENWAY, SULMAN, AND HIGGINS, in amended British patent No. 2,359, Feb. 1, 1909, described a process of flotation-concentration accelerated by the use of soluble frothing agents such as amyl acetate and other esters ; benzoic, valerianic and lactic acids ; acetones and other ketones such as camphor.

THEODORE JESSE HOOVER, in British patent No. 4,911, Feb. 27, 1909, described an apparatus for applying the frothing process. This is probably the most important mechanical development in the whole series, and together with its later improvements crystallizes the commercial application of the flotation method.

Greenway, Sulman & Higgins, in United States patent No. 962,678, April 30, 1909, duplicated British patent No. 2,359, Feb. 1, 1909.

Frank Wynne, in British Patent No. 12,266, May 25, 1909, described an oil-belt apparatus.

Jacob David Wolf, in British patent No. 15,469, July 2, 1909, described an improvement to his previous inventions.

Henry Howard Greenway, in British patent No. 21,856, Oct. 5, 1909, secured a patent for the use of alcohols with oleic acid and sulphuric acid in a flotation process.

Greenway & Lavers, in British patent No. 21,857, Oct. 20, 1909, secured a patent for the use of eucalyptus oil and other essential oils for flotation processes.

Greenway & Lavers, in U.S. patent No. 1,064,723, duplicated their British patent No. 21,857, Oct. 20, 1909.

Sulman & Picard, in British patent No. 26,019, Nov. 10, 1909, described a flotation treatment for oxidized ores.

Alfred Arthur Lockwood, in United States patent No. 956,773, Nov. 15, 1909, duplicated British patent No. 26,264, Dec. 4, 1908.

Henry Livingstone Sulman, in United States patent No. 955,012, Nov. 22, 1909, secured a patent for the use of amyl and other alcohols in an acid circuit in flotation processes.

Greenway & Lavers, in British patent No. 22,973, Dec. 1, 1909, secured a patent for using mixtures of fats, essential oils and alcohols in flotation processes.

Sulman, Higgins & Ballot, in British patent No. 28,933, Dec. 10, 1909, secured a patent for the use of a turpene product, such as spirits of turpentine, with or without resins, alcohols, phenols, oils or other soluble frothing agents.

Frank Burnett Dick, in British patent No. 2,500, Feb. 1, 1910, described an improvement to his invention for the treatment of copper ores described in his British patent No. 16,667 of 1908.

Henry Azor Wentworth, in United States patent No. 980,035, March 11, 1910, described a process of differential separation of mixed sulphides.

Theodore Jesse Hoover, in British patent No. 6,896, March 18, 1910, described a form of apparatus for flotation processes, being an improvement on British patent No. 4,911 of 1909.

Sulman & Picard, in British patent No. 8,650, April 9, 1910, described a process of preparing ores for flotation treatment, which consists in submitting them to a reducing roast.

Theodore Jesse Hoover, in British patent No. 10,929, May 3, 1910, described a form of apparatus for flotation processes—a further improvement on British patent No. 4,911 of 1909.

Alfred Arthur Lockwood, in British patent No. 13,009, May 28, 1910, described a new magnetic flotation method.

Greenway, Sulman & Higgins, in United States patent No. 962,678, June 28, 1910, duplicated British patent No. 2,359, Feb. 1, 1909.

Theodore Jesse Hoover, in United States patent No. 979,857, July 14, 1910, duplicated British patent No. 6,896, March 18, 1910.

Minerals Separation, Ltd., and Nutter, in British patent No. 23,870, Oct. 14, 1910, secured a patent for treating ores by flotation under varying conditions as to acidity, aeration, oil, and times of treatment, for the purpose of securing a differential separation of mixed sulphides.

Minerals Separation, Ltd., and Nutter, in British patent No. 2,393, Jan. 30, 1911, secured a patent for apparatus for flotation processes.

Murex Magnetic Co., Ltd., and Lockwood, in British patent No. 25,369, Nov. 14, 1911, patented a method of oiling metalliferous particles by means of shot in a revolving tube.

Alexander Herbert Smith, in United States patent No. 1,056,952, March 6, 1912, secured a patent for apparatus for flotation processes.

James M. Hyde, in United States patent No. 1,022,085, April 2, 1912, described an apparatus and flotation process where the acid required is added at some time and distance prior to the act of flotation. The patent contains the first description of an ingenious method of making high-grade concentrates and high recovery simultaneously.

Fleury James Lyster, in Commonwealth patent No. 5,040, May 21, 1912, secured a patent for the differential separation of lead and zinc sulphides by the use of eucalyptus oil in alkaline solutions.

Chapman & Tucker, in British patent No. 14,273, June 18, 1912, secured a patent for treating ores by flotation processes by first preparing the water used by agitating it with various substances, such as essential oils, and then subsequently treating by flotation in the ordinary way.

Minerals Separation, Ltd., in British patent No. 15,546, July 3, 1912, secured a patent for apparatus for flotation processes.

James Hebbard, in United States patent No. 1,064,209, Oct. 1, 1912, secured a patent for apparatus for flotation processes.

Karl Schick, in British patent No. 25,689, Nov. 8, 1912, secured a patent for a flotation process involving the use of benzol bichloride or trichloride, or chlorides of nitro-benzol.

Appelqvist & Tyden, in British patent No. 402, Jan. 6, 1913, patented a method and apparatus, using agitation, gasified oil, heat and high pressure, to produce flotation.

Robert Henry Jeffrey, in United States patent No. 1,052,061, Feb. 4, 1913, patented an apparatus for flotation processes.

CHRONOLOGICAL SUMMARY.

The following summary contains all the new ideas, mentioned in order of their appearance in patents : —

Haynes	1860	Selective action of oil for sulphides.
Bradford	1885	Flotation by the surface tension of water alone.
Everson	1885	Flotation by agitation, oil, and acid.
Hebron	1891	Effervescence.
Hockley	1892	Introduction of air.
Robson & Crowder	1894	Flotation in a pulp of oil.
Elmore	1898	Flotation by the buoyancy of oil.
Elmore	1901	Flotation by the buoyancy of oil, assisted by acidification.
Potter	1902	Flotation by gas-bubbles generated by acid, without oil.
Haultain & Stovel	1902	Greased belt.
Froment	1902	Agitation and acid-generated gas-bubbles, with oil.
Scammell	1902	Method of thickening oil.
Delprat	1902	Bubbles made by acid salt-cake.
Cattermole	1902	Granulation and sinking and differential separation by oil.
Elmore	1903	Buoyancy flotation with air excluded.
Wolf	1903	Apparatus for agitation froth production, with oil.
Goyder & Laughton	1903	Apparatus for acid flotation.
Cattermole, Sulman, & Picard	1903	Soap broken up into oil.

Sulman & Picard	1903	Oil added in form of spray.
Sulman & Picard	1903	Surface tension of water assisted by oil.
Kirby	1903	Air blown into oil pulp.
Elmore	1904	Gas generated by electrolysis.
Elmore	1904	Gas generated by vacuum.
Macquisten	1904	Tube apparatus.
Sulman, Picard & Ballot	1905	Small quantities of oil.
Sulman	1905	Air introduced by boiling.
Sulman, Picard & Ballot	1905	Super atmospheric pressure.
Ruthenberg	1907	Oil on table.
Lockwood & Samuel	1908	Magnetic paint.
Dick	1908	Reducing roast.
Horwood	1909	Sulphating roast.
Hoover	1910	Apparatus—agitator used as pump.
Hyde	1912	Re-treatment of concentrates.
Jeffrey	1913	Apparatus.

The other patents summarized in this chapter, while they contain many working details of great interest, do not in my opinion contain matter of great novelty. There are also several patents given in the chronological summary which are of doubtful novelty, especially those later than 1902.

CHAPTER III.

LITIGATION.

In the previous chapter 140 patents were summarized, but out of them it would not be possible to cull 140 new ideas. Besides the dearth of ideas, the question of priority and the fact of diffuse ownership were bound to give rise to a complicated mass of litigation.

The patent law has been one of the greatest accelerating factors in our modern civilization, because it has offered an adequate potential reward to individual effort. When inventions were few and widely differentiated, Governments were able to give adequate protection to the inventive class, there being in the nature of things little interference or clash of interests. However, after a hundred years of highly accelerated development, we have arrived at a point where it is obvious that either the patent idea or its method of operation has completely broken down. The historical situation is changed for another reason, namely, a patentee has to protect himself not only in his own country, but all over the world, and to conduct independent law-suits in each country.

Men nowadays work conscientiously and expend their energy in the development of ideas, only to learn later that these have already been the subject of patents, and that no new patent will be granted. The man who does this can attribute a part of his misfortune to his own fault, for the law presumes he has knowledge of precedent inventions. The individual who has received letters patent on an idea, however, and later finds that this brings him no reward when the matter is adjudicated in the courts, certainly deserves sympathy. He is in an entirely different position from the first man ; the Government has passed his invention as patentable, and if later the courts deprive him of the benefits definitely promised, someone has blundered. Every legal case in which the patents of one litigant are declared invalid is an indictment of the most serious nature against the system. Leaving out of account the victims of patent 'pirates'—unfortunately a large class—there are numerous well-intentioned people who have been deceived as to the value of the contract and covenant issued by the Government purporting to guarantee to them, their heirs and assigns, certain definite benefits and profits. The industrial world is alive to this breakdown, and a discussion of remedies has occupied the attention of serious reformers. The captains of industry have met this *impasse* in a measure by suppressed knowledge and secrecy in the arts. No better exposition of the iniquity of such secrecy can be made than that of James Douglas in the 'Transactions of the American Institute of Mining Engineers,' Vol. XXXIX., 1907. This paper is so able, and deals with a subject of such wide economic interest, that it deserves much wider circulation than it has had. Secrecy in the arts and the suppression of knowledge is grossly contrary to the public weal, and deteriorating to the individual. It threatens to stifle industrial development, because the incentive of the potential reward, to a large extent, is withdrawn. Sooner or later Governments must undertake to make their guarantees good. They must make the letters patent a contract as inviolable as the simple language on the face of it now would lead a sensible man to believe. The amount of money spent in patent litigation (including the expenses of the courts), and in the patent office of either the United States or Great Britain, is a heavy tax on industry, and it yields no economic result.

The men who are most competent to judge in these cases are not called until the matter is before the courts, technical and scientific men of ability and training generally being conspicuous by their absence. The patent commissioner, or chief, is generally a politician, whose chief ambition is to draw his salary with a minimum of effort.

Examination by the patent office should be thoroughly scientific. As no expert examiner has perfect knowledge, the specification, as determined by the official examiner, before final sealing should be published in the recognized technical press covering the particular subject of the patent, announcing that unless valid objections are submitted within six months the patent shall hold good from the date of publication, and be a perfect protection against any possibility of the patent ever being the subject of a law-suit. This would fix 'knowledge at the time', and prevent professional unearthing of old and abandoned ideas.

DECIDED CASES.

All the legal cases that in any way bear on the validity or ownership of this complex and tangled series of patents are here summarized:

ELMORE *v.* VAN METER.—The Elmore company, in 1902, opposed the granting of patents to Van Meter in Peru, but, after a hearing, the patents were granted. A compromise was subsequently effected between these two interests, by which the Van Meter patents were absorbed by Elmore.

SULMAN & PICARD *v.* WOLF.—Decision given in May, 1905. This was an action brought in the Chancery division of the English courts, before Mr. Justice Buckley, by Sulman & Picard, metallurgical chemists, against Wolf, inventor of a flotation process, for fees that Sulman & Picard claimed were due for work done on Wolf's process. Wolf counter-claimed that Sulman & Picard had violated their contract with him in that, being employed by him to investigate his process, they used the information obtained thereby, and took out patents in respect to certain discoveries that they made for him, and which they ought to have handed over to him. The counter-claim stated that this claim was unwarranted for the reason that Sulman & Picard had notified Wolf before he employed them that they were interested professionally and commercially in another similar oil process belonging to Minerals Separation, Ltd. They informed him that, in view of their opinion that this new process would prove superior to Wolf's, they did not feel justified in accepting fees from him, and suggested that he retain the services of someone else to conduct his trials. Nevertheless, Wolf entered into an agreement whereby Sulman & Picard were, among other things, to give him the benefit of all discoveries made in the course of their investigation of his process. The learned judge held that they had fulfilled every undertaking of the contract, and in the course of his judgment construed the meaning of various oil patents submitted to him as follows:

The Elmore process was for treating crushed ore by mixing with water and oil, so that the gangue shall become loaded with water and shall sink, and the sulphides shall become engaged by the oil, and shall float as by little rafts of oil. The process in which Wolf was interested was a process of the Elmore type, and was the subject of a patent by Scammell. Scammell's improvement on the Elmore process consisted in increasing the viscosity and cohesion, by treating the oil with sulphur chloride. As a result of the investigation of this Elmore–Scammell process by Sulman & Picard, Wolf ultimately took out a patent for a process that was of the Elmore-Scammell type, with this improvement: that after the oil had rafted off the sulphides, air was blown through the tailing to recover the oil that had been lost in the tailing. The other process that Sulman & Picard were investigating was different altogether. In this process, belonging to the Minerals Separation, Ltd., a very small quantity of oil was used, the original object being not to float the sulphides, but to collect the sulphides together in the form of granules and make them sink, adding just enough oil to act as a cement for the granules. Later this process was improved by the Minerals Separation, Ltd., in such a way that, by introducing air into the pulp, the granules could be made to float by the attached air-bubbles. This was not flotation by oil, but flotation by air. The only point of resemblance between the Elmore-Scammell-Wolf process and the process of Minerals Separation, Ltd., was that they both used a jet; but the object of the jet in Wolf's case was to recover lost oil, while in the other case it was used to make the sulphides float, and so recover them. The learned judge, therefore, held that Sulman & Picard had discharged every obligation faithfully, and that Wolf must pay the fees agreed upon.

DE BAVAY *v.* MACQUISTEN. Decision delivered in Jan., 1907. Macquisten applied for a patent in Australia for his process, which involved the use of the surface tension of water applied in a slowly revolving tube. De Bavay opposed the granting of this patent, but, after hearing the evidence of both parties, the Commissioner decided that Macquisten was entitled to his patent.

POTTER *v.* THE BROKEN HILL PROPRIETARY COMPANY. Decision delivered in February, 1907. This was an action brought in Australia by Charles V. Potter, inventor of an acid-flotation process, against the Proprietary company for infringement by the use of the Delprat process. Delprat pleaded that Potter's patent was invalid because:

(1) It will not do as much as it professes to do with any sulphide ores.

(2) With some sulphide ores it will not work at all.

(3) With many sulphide ores it will not work with any result that could be useful.

(4) It will not work with the class of ore mentioned in the specification.

(5) It will not work with slime.

(6) Although the patentee says that any acid may be used,

some acids will not be operative, and an acid that will be operative on one ore will not be operative on another.

Much detailed evidence was presented to the Court on these points, and Mr. Justice à Beckett decided that Potter's patent was invalid on account of want of utility, for the following reasons :

"(*a*) That with many ores no such separation can be "effected, although partial separation can be effected.

"(*b*) That in many instances in which high percentages of "separation have been obtained in flotation of sulphides a large "percentage of gangue has been floated with the sulphides.

"(*c*) That some ores are not amenable to the process under "any condition.

"(*d*) That in cases in which only part of the sulphides are "floated no reason can be assigned for the other part of the sul-"phides failing to float, and no repetition or variation of the "process will make this part float.

"(*e*) That no assay or examination of a particular ore will "enable an operator to discover whether with that ore the process "will be successful wholly or partially, or will fail altogether."

On the other hand, the court held that the Delprat process would have been an infringement if Potter's patent had not been invalid by reason of having been badly drawn up. There was no question but that Potter had a novel idea.

This unsatisfactory decision was at once appealed to the High Court of Australia, but before the High Court was called upon to revise the findings of Mr. Justice à Beckett, a compromise was effected as follows :—

(1) Potter granted to the Proprietary company the right to use his process free in Australia.

(2) The Proprietary company assigned to Potter all the Delprat patents in Australia.

(3) The Proprietary company paid Potter £10,000 in cash.

(4) Each party paid its own costs.

In view of the compromise it would seem that the defendants had little confidence in Mr. Justice à Beckett's decision.

ORE CONCENTRATION COMPANY, LTD., *v.* WEBSTER AND OTHERS. Decision rendered in October, 1908. This was a suit brought in the King's Bench division of the English courts before Mr. Justice Darling by the owners of the Elmore process against Webster and others for damages for non-fulfilment of contract. The Elmore company and Webster *et al.* had entered into a contract some years before, wherein Webster *et al.* were given an option on the rights of the old Elmore process for Australia at a fixed price, and were to be allowed to inspect and investigate the Elmore process previous to exercising the option. Among other clauses in the option was one providing that any patents for improvements in oil-concentration acquired in any way by Webster and associates should become the property of the Elmore company, and be treated for the purpose of the option as if they were the original patents. After investigating the Elmore process for some time, Webster and associates came to the conclusion that it was not what they wanted, and they allowed their option to expire, and so waived all their rights and lost the payments they had already made. Some time later, A. E. Cattermole brought on the market his oil process, and after offering unsuccessfully to sell the patent rights to the Elmore company and others, he offered them to Webster and associates. After due consideration, Webster and associates formed a syndicate, into which they took a number of other people, and this syndicate purchased the Cattermole, Froment, Sulman & Picard, and other oil-process patents. Webster and Ballot, two of the holders of the old option on the Elmore process for Australia, were directors of the new syndicate, which was called Minerals Separation, Ltd. The Elmore company then brought a suit against Webster, Ballot, and Hay, to enforce the clause in the contract above mentioned.

After hearing evidence on the negotiations leading up to the option, Mr. Justice Darling delivered judgment to the effect that the particular clause had been introduced into the contract without authority after it had been signed, sealed, and delivered by both parties, and that therefore the Elmore company was not entitled to any redress.

The Elmore company appealed from Mr. Justice Darling's decision to the Court of Appeal, which court, after hearing the arguments of counsel, ordered that the judgment of Mr. Justice Darling be set aside and a new trial held.

The new trial was held in the Chancery division of the English courts before Mr. Justice Parker. In this trial the Elmore company introduced evidence to show that the Minerals Separation processes were oil-flotation processes, similar to the Elmore processes, and that they belonged rightfully to the Elmore company under the terms of the clause of the option above-mentioned. Webster and associates introduced evidence to show that they had never owned these patents; that they were never in their possession; but had been bought by a trustee of the syndicate, and had passed directly from the inventors through a trustee to the Minerals Separation Syndicate. When the proceedings reached this stage, the learned counsel for the plaintiffs asked the Court for a moment to confer with the learned counsel for the defendants. Thereupon it was mutually agreed between the plaintiffs, the defendants, and the Court, that the proceedings be stayed on the following terms:

That both parties to the action pay their own costs.

That the option agreement be treated as if the clause referred to were struck out altogether.

The result of this piece of litigation leaves the impression that it was unnecessary and wasteful.

ELMORE *v.* MINERALS SEPARATION, LTD. Decision delivered May, 1909. The Minerals Separation, Ltd., through Sulman, Picard, and Ballot, applied for a patent in Germany. This was opposed by Elmore, but the patent was granted. The Elmore company appealed from the decision of the Patent Office to a higher court, which reversed the decision of the Patent Office.

MINERALS SEPARATION, LTD., *v.* NORRIS. Decision rendered May, 1909. Dudley Norris applied for a patent in England for a method of introducing air into an oiled pulp. This was opposed by the Minerals Separation, Ltd., and after hearing evidence the law officer held that practically all but one of Norris's claims were anticipated by the earlier patents of Hoover & Sulman.

MINERALS SEPARATION, LTD., *v.* POTTER. Decision rendered July, 1909. After the Potter company had compromised with the Delprat interests, they applied for amendments in Australia with a view to overcoming the invalidity in their patents as indicated by Mr. Justice à Beckett. These amendments were opposed by the Minerals Separation, Ltd. The case was heard before the Commissioner of Patents, and some of the amendments were granted and others rejected. The Minerals Separation, Ltd., appealed from the decision of the Commissioner to the High Court of Australia, and this court decided in favour of Potter, and the amendment was granted. In December, 1909, Minerals Separation, Ltd., applied to the Privy Council in London for permission to appeal from the High Court of Australia, but the application was denied, on the grounds that the case could only come before them on a question of infringement.

British Ore Concentration Syndicate, Ltd., and Alexander Stanley Elmore, *v.* The Minerals Separation, Ltd. Decision rendered in November, 1909. This was a suit brought by the Elmore interests, owners of an oil-concentration process, asking for "an injunction restraining the defendants from using "ores or mineral substances treated by any one of the processes "described and claimed respectively in the specifications of "letters patent No. 21,948 of 1898, and 6,519 of 1901, of which "the plaintiffs are the registered legal owners." The trial case was heard in July, 1908, by Mr. Justice Neville, of the High Court of Chancery, who, after an inquiry lasting seven days, pronounced judgment to the effect that the Minerals Separation, Ltd., owners of the Minerals Separation process, were not infringing. In his judgment Mr. Justice Neville made the following points :

(1) The selective action of oil for sulphides was known before Elmore obtained his patents, and was disclosed in prior expired patents.

(2) Elmore's patent was for a process wherein a large quantity of oil was used, sufficient to carry all the sulphides to the surface by the buoyancy of the oil.

(3) The Minerals Separation process used only an infinitesimal amount of oil for the purpose of attaching air-bubbles to the sulphides, and so causing them to float by the buoyancy of the air-bubbles.

(4) The use of acid in oil processes was known before Elmore obtained his patents and was disclosed in prior, expired patents.

Mr. Justice Neville then summed up in these words :

"I think, therefore, in that case, whether you take it that "the patent is confined to the 1898 patent, or whether you take "it generally, the defendants have not infringed, or they have "infringed a patent which has no validity, and consequently no "relief can be granted against them."

The plaintiffs (the Elmore company) appealed from this decision and the appeal was heard in the Court of Appeal before the Master of the Rolls, Lord Justice Fletcher Moulton, and Lord Justice Farwell, in November, 1908. Judgment was rendered on December 2, reversing the decision of the lower court and finding that Minerals Separation, Ltd., were not infringing the 1898 patent, but were infringing the 1901 patent. An injunction was granted as applied for. Lord Justice Fletcher Moulton's idea of the patents in question was as follows :—

(1) That the first Elmore patent was not anticipated by previous, expired patents.

(2) That if Minerals Separation used a thin oil they would not infringe Elmore.

(3) That the second Elmore patent was not anticipated by previous, expired patents.

(4) That the Minerals Separation infringed the second patent by using acid.

The Court of Appeal thereupon reversed Mr. Justice Neville's decision and granted the injunction against Minerals Separation, Ltd.

The Minerals Separation, Ltd., appealed from this decision to the House of Lords—the court of last resort—and on November 16, 1909, the Lord Chancellor and Lords Halsbury, Ashbourne, Atkinson, and Shaw, reversed the judgment of the Court of Appeal and upheld the judgment of the trial court as follows :

The Lord Chancellor held that the Elmore patents were drawn up with great subtlety, in order that the claims might be expanded or contracted as occasion might require in the interests of the patentee ; that the only definite claim in the patent was for acidulation, and that this was anticipated in the expired Everson patent ; therefore the Elmore patents could not be sustained.

Lord Halsbury held that the Elmore and the Minerals Separation processes were essentially different, in that the one was based on the selective action of oil, and the other on surface tension ; that Elmore had no valid claim to acidulation, because it was known and had been previously described ; that the Elmore patent should not be upheld, if for no other reason than because of its ambiguity.

Lord Atkinson held that the Elmore process was the addition of a small quantity of acid and a relatively large quantity of oil to a mixture of ore and water, where the oil, in accordance with some obscure law of affinity, seized upon the minute particles of ore in preference to the earthy particles, and, by the buoyancy of oil, floated them to the surface ; that the Minerals Separation did not infringe this process, because their process was one where they made use of the known selective action of oil, yet the oil was used in relatively small quantities, and the metallic particles were only coated with a thin film of it, and the lifting force was found, not in the buoyancy of the oil, but in the natural buoyancy of the air-bubbles, which, introduced into the mass by violent agitation, envelop or become attached to the oiled mineral particles and raise them to the surface.

Lord Shaw held that the two processes were essentially different, so much so, that apart from the question of the prior state of knowledge of the art, there was no infringement.

Lord Ashbourne concurred with the decision of their lordships, thus making the judgment of the Court unanimous.

ELMORE *v.* THE SULPHIDE CORPORATION, LTD. The Elmore company filed a writ in Australia alleging that the Sulphide Corporation is infringing the Elmore patents by the use of the Minerals Separation process. One cannot do better than quote *The Mining Magazine* for March 1914:

"After litigation lasting for six years, the Minerals Separation flotation process has been declared by the highest courts of the British Empire, the House of Lords and the Judicial Committee of the Privy Council, to constitute an invention independent of anything done before. The actions were brought by the Ore Concentration Company, the owners of the Elmore patents, the claim in the English courts being that their patents of 1898 and 1901 covered the use of oil in flotation processes and the application of acid for enhancing the selective action of oil for metallic and sulphide surfaces. The Chancery Court ruled against the claim that both patents covered the Minerals Separation process; the Court of Appeal ruled against the patent of 1898, but held that the patent of 1901 covered the use of acid for increasing the affinity of oil for metallic and sulphide particles; the House of Lords reversed the judgment of the Court of Appeal, and restored that of the Court of Chancery. Subsequently action was commenced in New South Wales. In this litigation the oil claim was dropped, and the argument was centred on the use of acid for the purpose mentioned above. The Australian Court was against the Elmores, who forthwith appealed to the Judicial Committee of the Privy Council. The appeal was heard in November last, but for some reason not disclosed a judgment was not given, and the case was re-argued last month before a larger court. The judgment of this Court confirmed that of the Australian judge, the appeal being dismissed. With regard to the judgments of the House of Lords and the Judicial Committee of the Privy Council, we are free to say that many engineers have expressed surprise at their tone and methods, especially those who have known something of the earlier internal history of the practical development of the flotation idea. The

Judges of the House of Lords were unnecessarily offensive when they referred to tricky and subtle methods of preparing specifications and claims. The Judicial Committee of the Privy Council, during the hearings, appeared to be desirous of confining the arguments to the acid specification, and the impression gained by the audience, and even by the lawyers engaged in the case, was that the arguments in favour of the Elmores' claim were making an impression. The judgment upholding the Australian decision and maintaining the independence of the Minerals Separation process came, therefore, as a surprise to everyone, including the litigants on both sides. For the benefit of our readers we ought to explain that the Elmore patents of 1898 and 1901 referred solely to the original process wherein large bodies of oil were used to raise the metallic and sulphide particles, and that their patents of 1904 introducing their improved method known as the vacuum process were not cited in the legal arguments. No doubt there were good and sufficient reasons for not referring to the improved process, though, seeing that the chief Minerals Separation patent, granted to Messrs. Sulman, Picard, and Ballot, was of later date, namely, 1905, we think a mention of it would have been of value when surveying the broad field of flotation as distinct from the consideration of the narrower scope of the 1901 patent. As the Judicial Committee's actual judgment was based on this broad view, and not on the narrower arguments that occupied the greater part of counsel's time, an impression is created that the arguments and judgment were at cross-purposes. We are also left in doubt as to whether the five members of the Judicial Committee were unanimous, for the custom of that imperial tribunal differs from that of the English Courts, where each member gives his opinion. We have not the space to quote the judgment in full, but we can refer our reader, to the issue of *The Financial Times* of March 7th, where the full text appears. Suffice it to say that the Everson patent was held not to be an anticipation of the Elmore acid patent; but, on the other hand, that the Minerals Separation process was not an infringement of the Elmore patent, because it relied on surface tension, and not oil, for the flotation effect. The Elmore vacuum process depends just as much on surface tension as the Minerals Separation process; hence our remark that the judges should have included it within their broad view. We feel bound, however, to say, from our knowledge of the investigations and negotiations of earlier days, that the Elmores have not received the kindest treatment by the law or the most generous consideration of those that are now their enemies."

This judgment is perfectly clear that the Minerals Separation, Ltd., does not infringe the early Elmore patents. The arguments in favour of this view will, however, not appeal to engineers using the processes as being at all well grounded. If, as a simple reading of the judgment would warrant, it is argued that the use of oil is "entirely and absolutely unessential," one could with equal right argue on the facts that water is unessential, that acid is unessential, that air is unessential, and that even the ore itself is unessential to the successful working of the process, and that the only really essential factor is "surface tension." This latter factor was, however, amply disclosed by Hezekiah Bradford years ago.

POTTER *v.* THE SULPHIDE CORPORATION, LTD. The Potter Sulphide Process Co. filed a writ in Australia alleging that the Sulphide Corporation is infringing the Potter patents by the use of the Minerals Separation process. This suit has now been withdrawn as a result of the amalgamation of the interests involved.

MINERALS SEPARATION, LTD., *v.* DE BAVAY. The Minerals Separation, Ltd., filed a writ in Australia alleging that the Amalgamated Zinc, Ltd., is infringing the Minerals Separation patents by the use of the De Bavay process. This suit also has been withdrawn as a result of the amalgamation of the interests involved.

THE MINERALS SEPARATION CO., LTD., *v.* JAMES M. HYDE. Decision delivered in August, 1913. This was a suit brought in the United States District Court, District of Montana, by the above Company against Hyde for infringement of their patents. There does not seem to be any logical reason why this suit was brought against Hyde, as he was not the user of any process, and had no interest in the Company which was the user, the user of the alleged infringement being the Butte and Superior Mining Company, of Butte, Montana.

The judgment given by Judge Bourguin seems to rest on the question of whether the Froment patents constitute an anticipation of the Sulman & Picard patent of 1905. Patents other than Froment prior to that date seem to have been given little consideration by either contestants or the learned judges. The important part of the judgment is as follows :—"The claims are general and particular, all calling for oil and agitation to produce a froth, some defining a range or quantities of oily substance, some likewise of acid, some specifying oily substance alone, some oily substances in various combinations with heat or acid and with both. The main defence of invalidity is lack of novelty and anticipation. In reference thereto it appears from the evidence that the use of oil, air, and agitation in ore concentration, separately and in various combinations, and with other ingredients, was well known to the art prior to the discovery of the process in suit. To fully summarise the prior processes, some of them were bulk oil processes, using oil in such large quantities that in taking up the metalliferous particles in the pulp the mass thereof was sufficiently buoyant to float to the surface of water, the gangue sinking. Concentration being more essential for lean ores, economy is the foundation of success, so other of these processes reduced the amount of oil to a degree where it was not sufficient of itself to float the metal and to aid therein, air, steam, or gas was injected to render the mass spongy. Another process further reduced the oil, and to and around 4 to 6 per cent. in weight of the weight of the metalliferous content of the ore, the somewhat novel result being that the metalliferous particles were by the oil agglomerated into granules which sank in the water, and were retained in the mixing vessel, while the gangue rose and was carried off by upcast. Some dispensed with oil and employed surface tension or skin flotation by floating off the powdered metalliferous particles on the surface of quietly flowing waters, or by injecting air, steam, or gas into the mixture of ore and water, or by generating gas therein, where bubbles attached to said particles and carried them to the surface of the water, in all the gangue sinking. Another process sought the same end by spraying the oiled metalliferous particles through air and on to water where they remained, the gangue sinking. In some processes gangue was used to generate gas *in situ* for flotation, while in others it was used solely to render more pronounced the selective attribute of oil for metal over gangue.

Froment's requires several times the quantity of oil than does this in suit, both by examination of the patents and working description and by tests in evidence. Froment crushes the ore in two operations, and deslimes it before treatment, because the slime is too fine to be treated by his process, while the process in suit needs but one crushing operation, and finds slime advantageous and most easily recovered. Froment employs carbonate of lime; the process in suit does not. Froment required acid, and in greater quantity and for a different function than does the process in suit, which latter may or may not use acid. Both may use heat, and both require agitation—Froment agitation only to disseminate the oil, the process in suit for that purpose and also to aerate. Froment's result is by flotation by gas generated *in situ*; this in suit is by flotation by air introduced by vigorous agitation. Froment's product is like unto a magma, a spongy, pasty mass of oil and metallic particles, and more or less gas bubbles, while this in suit is a froth of oil and metallic particles and air bubbles. Froment's requires oil in such quantity that he deems it worthy of recovery from the concentrate, so far as it can be; this in suit so little oil it disappears, is not sensible to sight or touch upon the concentrate, but only to analysis. In Froment's it would seem that the metallic particles are floated like the basket of a balloon, while in this like the very envelope of a balloon. Froment's is costly, while this is cheap. And from the evidence it would seem that Froment's process would fail in practical operation, while this in suit has succeeded. In Froment's he oils the metallic particles by agitation; then, when the mixture is quiescent, generates gas therein by quick reaction, followed by immediate and direct rising of the gas bubbles to the surface in which they may come into contact with but few metallic particles. In this in suit vigorous agitation of the mixture beats great and excess volumes of air therein, likely to bringing the ultimate air bubbles into repeated contact with many metallic particles. The action of the gas in Froment's is almost explosive in nature. He speaks of proportion of carbonate of lime to be sought as, in his test tube example, the reaction may be so sudden and violent as to project the metallic particles out of the tube. Froment's gas bubbles, quick formed and quick rising it may be, arrive at the surface with expansion still in progress. These or analogous reasons may account for Froment's magma breaking gas bubbles and fragile evanescent froth in so far as his result is like unto froth, and also may account for the process in suit's strong and lasting froth."

As a conclusion and verdict the Honourable Judge then concludes: "The circumstances are sufficient to constitute these patentees joint discoverers. At any rate, it is not proven they are not. Although some of the claims in issue include elements not absolutely essential, namely, heat and acid, and in respect to which they may afford no protection, they are not invalidated by undeceiving superfluous features, if heat and acid are such. The patent is valid in respect to all claims in issue. Enough appears in the evidence to compel the conclusion defendant was using complainants' process and was infringing the claims in issue as charged."

This verdict has the merit, if substantiated on appeal, of limiting the monopoly of the predominant exponent to a degree whereby there is still scope for profitable invention.

There are many points in this decision which, obviously, would not satisfy an independent critic, and it is not surprising that the loser should appeal to a court of more matured judgment and dignity. This appeal was heard in May, 1914, before the United States Court of Appeals for the Ninth Circuit in San Francisco. The Court was composed of Circuit Judges Gilbert and Ross and District Judge Dietrich.

In the whole history of flotation process litigation this is the first time that the Court has taken a broad view of all the patents having a bearing on the case, and the first time a pronouncement has been made which gives the user an idea as to whom he must pay royalties, if any are necessary. The decision was written by Judge Gilbert, and is so clear and forcible and indicates such a complete grasp of the subject that it is given in full, as follows :

This is an appeal from the decree of the Court below sustaining Letters Patent No. 835,120, issued to Sulman, Picard, and Ballot, on November 6, 1906, and assigned to Minerals Separation, Limited, and Minerals Separation American Syndicate, Limited, adjudging the appellant herein to have infringed the same, and enjoining further infringement. The patent is for new and useful improvements in ore concentration. Its object is to separate metalliferous matter from gangue by means of oils and fatty acids which have a preferential affinity for metalliferous matter. In the specification reference is made to United States Letters Patent No. 777,273, granted to A. E. Cattermole. The Cattermole patent specifies that an amount of oil varying from four per cent. to six per cent. of the weight of metalliferous matter present is agitated with an ore pulp, so as to form granules which can be separated from the gangue. The specifications of the patent in suit state that the inventors have found that "if the proportion of oily substance be considerably reduced—say to a fraction of one per cent. on the ore—granulation ceases to take place, and after vigorous agitation there is a tendency for a part of the oil-coated metalliferous matter to rise to the surface of the pulp in the form of a froth or scum," and the specifications add : "The proportion of mineral which floats in the form of froth varies considerably with different ores and with different oily substances, and before utilizing the facts above mentioned in the concentration of any particular ore a simple preliminary test is necessary to determine which oily substance yields the proportion of froth or scum desired." There are thirteen claims in the patent. The first is "the herein described process of concentrating ores, which consists in mixing the powdered ore with water, adding a small proportion of an oily liquid having a preferential affinity for metalliferous matter (amounting to a fraction of one per cent. on the ore), agitating the mixture until the oil-coated mineral matter forms into a froth, and separating the froth from the remainder by flotation." The next three claims specify the quantity of oil as amounting to "a fraction of one per cent. on the ore." The second claim adds to the first the use of slightly acidified water. The third adds to the second, "warming the mixture." The fourth adds to the third "and removing the oily coating from the mineral." The fifth specifies the oil as "oleic acid of a quantity of from 0.025-0.5 per cent. on the ore." The sixth adds to the fifth the use of water containing one per cent. of sulphuric acid. The seventh adds "warming the mixture to 30°-40° Centigrade." The eighth specifies the use of oleic-soap solution to produce oleic acid, "amounting to 0.02-0.5 per cent." The ninth is "the process of concentrating powdered ores which consists in separating the mineral from the gangue by coating the mineral with oil in water containing a small quantity of oil, agitating the mixture to form a froth and separating the froth." The tenth adds to the ninth, "warming the mixture"; and the eleventh adds the use of acid. The twelfth adds "separating the froth from the remainder of the mixture," and the thirteenth adds a current of water to carry off the coarser minerals, and "filtering off the froth and removing the oleic acid therefrom by treatment with an alkali."

The answer of the appellant denied that Sulman, Picard, and Ballot were the first inventors of the process, or that there was any invention described in the patent, and denied infringement, and alleged that the process described in the patent was old and not patentable; that the process had been included in certain patents which were enumerated in the answer. The appellant was adjudged to have infringed Claims numbered 1, 2, 3, 5, 6, 7, 9, 10, 11 and 12.

The appellees' process depends primarily upon the affinity of oil for the metalliferous portion of powdered ore when mixed with water. It is conceded that that affinity and the fact that oil will carry the metalliferous portions to the surface of the mixture, while the rock or gangue will sink, have been known for many years. That which is presented as new in the patent, and as the pivotal discovery on which its validity depends, is the formation of a froth or scum containing the metalliferous matter produced by agitation of the pulverized ore in water by the action of oil in a quantity less than one per cent. of the quantity of ore treated.

Turning to the patents which are adverted to as showing the prior art, we find the following: The British patent to Haynes, No. 488, issued in 1860, recommends the use of from 11 to 25 per cent. of oil by weight to the finely powdered ore, the mixture to be agitated with water, either warm or cold, until the earthy matter sinks and the metal is gathered by the oil. In that process the sunken earthy matter is removed, fresh ore is replaced, and the operation repeated with the same oil until it will take up no more metalliferous matter. The United States patent, No. 348,157, issued to Everson in 1886, specifies the use of oil in quantities varying from five to eighteen per cent. Miss Everson was the first to make the important discovery that the affinity of the oil for the metal was increased by the addition of an acid. In the description of her process she states that in the operation the mass is broken up and thoroughly stirred in water in a vessel provided with a mechanical stirrer, and having an outlet or outlets at the bottom for the escape of the water and sand. The Schwartz United States Patent No. 807,503, applied for in May, 1904, and granted in December, 1905, describes a process in which the dry ore is first mixed with enough oil to make a thick pasty mass, and water is thereafter added, and the mass is agitated so as to cause the metallic particles to float. The quantity of oil to be used is not further specified, but it is in the testimony that the Schwartz process has been experimentally used with cotton seed oil, the quantity used being 3.6 per cent. of the ore treated. The United States patent to Kirby, No. 809,959, was applied for December 14, 1903, and granted January 16, 1906. The oil used by Kirby was kerosene oil, in which five per cent. of bitumen was dissolved. One of the claims is as follows: "The process of separating minerals, which consists in mixing together the pulverized mineral material, a considerable quantity of water and a solution of bitumen in a distillable hydrocarbon liquid, the proportion of bitumen in solution being substantially sufficient to ensure the coating and entrainment of the mineral particles; and allowing the same to settle, and removing therefrom the floating layer of said solution and the mineral particles which have been coated thereby." In his specifications he says: "These materials to be so thoroughly agitated together as to finely subdivide said solution into small globules, and bring said globules into contact with substantially all of the pulverized mineral particles, which will by preference adhere to them." And in describing the means for the agitation he specified a "vertically rotating shaft" in the mixing tank, which it is said is to be "rotated rapidly." No specific quantity of oil is prescribed, but it is stated in the specifications that a sufficient amount of the kerosene and bitumen in solution is to be used, "excellent results being obtained by using one-fourth to three-fourths as much by weight as ore." In the Froment Italian patent, issued May 20, 1902, and the British patent to Froment, issued June 4, 1903, the invention described is declared to consist "of a modification of what is known as the oil process of ore concentration." The modification consisted in releasing gas from the finely powdered ore, and "adding a suitable oil," resulting in a flotation of the oil and metal to the surface. Froment mentions the use of gas to aid in the flotation of sulphides reduced to powder and moistened by a fatty substance, in explanation of which the patentee says that if, for example, in a test tube there is placed ten grams of sulphuretted copper ore, with its gangue, a gram of limestone, the whole reduced to powder, and there is added thereto 30 grams of water, a few drops of sulphuric acid "and a thin layer of ordinary oil," and the mixture is agitated for a second, the whole of the copper pyrite will instantly rise to the top of the liquid. The patentees of the appellees' patent purchased from Froment on November 17, 1903, the Froment patent, and Froment agreed to send all possible information, together with the plans, drawings and a model plant to England for the use of the purchasers. The agreement was carried out in December, 1903. The instructions which Froment sent contain the following: "If the ore contains more than five per cent. of metallic matter, such as copper, or lead, it will be necessary to use a little more oil. As a general rule, one may assume 1% of oil for ore containing up to 5% of metals, 1½% of oil for ore containing up to 10%, and so on, up to ores containing 50% of metallic lead, which it was said would require 3½% of oil." In the instructions the mixing device is described as composed of a cylindrical body made of strong sheet iron, riveted with bolts, "in which two stirring devices work in opposite directions, making about 300 revolutions per minute." The Cattermole process, which is referred to in the Letters Patent in controversy in this suit, is presented in two United States patents, one No. 777,273 and one No. 777,274, both of date December 13, 1904. The amount of oil specified in the Cattermole process is from four to six per cent. of the weight of metalliferous mineral matter present in the ore. This quantity with the average ores would be less than one per cent. of the mass treated. The fact that the final purpose of the Cattermole process is to increase the sinking tendency of the metalliferous mineral instead of removing it upon the surface does not render that process any less instructive as to the state of the prior art, for there are two distinct steps in the treatment of the ore—there is first a violent agitation to cause the oil to gather up the metalliferous particles, as in the case of other oil flotation processes. Then follows a slow, smooth stirring of the mass, which releases the air from the froth or scum, and causes the oil and metalliferous particles to adhere together and form granules of sufficient size and weight to sink, after which the mass at the bottom is drawn off, and the particles of sand and gangue therein are forced upward and thus separated from the granules of metal. Here is described a process in which the quantity of oil used approximates the quantity which is called for by the appellees' patent, a fraction of one per cent.

When the claims and the description of the process of the appellees' patent are compared with the patents of the prior art, it will be seen that the only material difference is in the smaller quantity of oil which the appellees use. Comparing the appellees' process with the Froment process, it will be seen that in both powdered ore is mixed with a sufficient water to form a freely flowing pulp; that while Froment recommends the use of oil of from one per cent. to 3½ per cent. of the ore by weight, the appellees recommend a fraction of one per cent. of oil; that Froment recommends the use of ordinary oil or a suitable oil, while the appellees' patent mentions oils, fatty acids and oleic acid; that in both processes there is agitation of the mixture; that in both processes a small quantity of sulphuric acid is recommended; that in both processes the mixture of all the substances is made before the agitation; and that in both processes bubbles of air or gas are caught in the sulphides in the form of a froth which rises to the surface. So also in the Kirby patent, the various steps of the process are similarly described. We find there the pulverization of the ore, mixing it with water to form a floating pulp, mixing therewith kerosene oil with a small percentage of bitumen, violently agitating the mass so as to bring the oil into contact with the mineral particles of the ore, causing the oil-coated mineral particles to rise and float on the surface of the water, while the gangue sinks to the bottom; and, lastly, skimming the floating concentrate from the surface of the liquid. But the appellees say that the Froment patent is a paper patent; and that, therefore, it is to be disregarded. A paper patent, if it fully describes an invention, whether it be a machine, device or process, is just as effective to show anticipation as a patent which describes an invention which has gone into extensive use, for a presumption of operativeness and of some utility attends the granting of Letters Patent. *Packard* v. *Lacing Stud Co.*, 70 Fed., 66; *E. L. Watrous Mfg. Co.* v. *American Hardware Mfg. Co.*, 161 Fed., 362; *National Chemical & Fertiliser Co.* v. *Swift & Co.*, 104 Fed., 87, 91; *Universal Winding Co.* v. *Willimantic Linen Co.*, 82 Fed., 228; *Van Epps* v. *United Box Board & Paper Co.*, 143 Fed., 869; *Ironclad Mfg. Co.* v. *Dairyman's Mfg. Co.*, 143 Fed., 512, 515; *Dashiell* v. *Grosvenor*, 162 U.S., 425, 432. In Telephone cases, 126 U. S., 1, 536, it was said: " The law does not require that a discoverer or inventor, in order to get a patent for a process, must have succeeded in bringing his art to the highest degree of perfection. It is enough if he describes his method with sufficient clearness and precision to enable those skilled in the matter to understand what the process is, and if he points out some practicable way of putting it into operation."

The fact that the appellees use a smaller quantity of oil than was used in the prior art is not of itself, and it is not claimed by them to be, sufficient to distinguish their process so as to render it patentable. To discover that the desired result may be accomplished with the use of a fraction of one per cent. of oil when formerly a much larger quantity of oil had been used, and had been deemed necessary, is not an invention or discovery within the meaning of the patent laws. It is a difference of degree, and not of kind. " A change only in form, proportions, or degree, doing substantially the same thing in the same way by substantially the same means with better results is not such invention as will sustain a patent." *Roberts* v. *Ryer*, 91 U. S., 150.

In *Fried. Krupp Aktien-Gesellschaft* v. *Midvale Steel Co.*, 191 Fed., 588, the Court said: " But mere useful and economical administrative methods, however valuable, while they may, and usually are incident to invention, do not themselves constitute invention." And in *DeLamar* v. *DeLamar Min. Co., Ltd.*, 117 Fed., 240–248, this court, referring to the use of zinc dust for the purpose of precipitating mineral in a solution, said: "The right to use the dust being free to all, we think it follows necessarily that all have a right to adjust the quantity of the material to the necessities of each case, and ascertain by experiment or analysis, if need be, the quantity that may be required to produce the desired end; that such a use cannot be made the subject of monopoly, there being involved in it no discovery, but only the exercise of ordinary prudence and skill." See also *Brady Brass Co.* v. *Ajax Metal Co.*, 160 Fed., 84; *Commercial Mfg. Co.* v. *Fairbank Co.*, 135 U. S., 176; *Bullock Electric Mfg. Co.* v. *General Electric Co.*, 149 Fed., 408; *Lauman* v. *Urschel White Lime Co.*, 136 Fed., 190; *Tilghman* v. *Proctor*, 102 U. S., 707; *Guidet* v. *Brooklyn*, 105 U. S., 550.

But it is said that the appellees' process is the only froth process, and that the processes described in the prior art are the bulk flotation or oil buoyancy process. We have to inquire, therefore, what is the oil buoyancy process? It is described in the Elmore patents, No. 676,679, issued June 18, 1901, and No. 689,070, issued December 17, 1901, and in the testimony of Mr. Ballantyne, General Patent Counsel of the Appellees. Mr. Ballantyne said that it was essential to this process—first, that the oil should be thick and viscous, for otherwise the metal would easily fall out of the oil; second, that the process be carried out in the cold, because if the oil be heated it becomes thin, and will not entrap or float the mineral; third, that the mingling of the pulp and the oil be as gentle as possible, so to avoid breaking the oil into globules. And the appellees' expert, Dr. Chandler, testified that in the oil bulk flotation, 15.7 parts of oil must be used to 6.7 parts of ore. With these definitions and explanations of the oil buoyancy process in view, it is very plainly to be seen that in none of the patents herein discussed, aside from the Elmores', is that process used. The Haynes patent uses 11 per cent. of oil to the ore, and directs that the mixture be agitated with hot, warm or cold water. Kirby recommends thorough agitation by rapid rotation of the agitator, and he refers to the floating concentrate as a "scum." The Everson patent declares that thorough agitation of the mass or pulp comprising water, the finely-divided ore, the oil of fat and the acid, is necessary, and in the *Engineering and Mining Journal* of November 15, 1890, there is an article describing a test operation of that process, in which it was said that as the result thereof "a thick scum of sulphurets rose to the surface and was skimmed off, leaving the hitherto black ore as white as snow; in fact, pure silica." And so in the Cattermole process, although its ultimate purpose was to precipitate the metal in the form of granules to the bottom of the tank it was first required that the mixture be thoroughly agitated, and as the result thereof a froth necessarily came to the surface.

The contention is made, however, that if indeed the prior patents disclose froth processes, the scum which the appellees' process causes to rise to the surface of the water is so different from the froth or scum which arises under the prior art that it is a new result, and is not anticipated by anything in the prior art. Say counsel for the appellees: "You produce a froth which is not our froth," and again they say that the appellees' froth is "a pure metal froth," while that of the other patents is an "oil froth," and that the appellees' froth consists of air bubbles surrounded by metal armor without any appreciable quantity of oil connected therewith. The evidence in the case, together with the illustration thereof afforded by demonstrations of the various processes which were made in the aid of the argument before this court, convince us that the froth in all these processes is the same, with the exception that there is less oil (as there must necessarily be) in the appellees' froth than in the others. The froths are all similar in appearance; they all rise to the surface after the same amount of agitation; they all gather with equal efficiency the same quantity of metal, and all may be removed from the surface in the same way. It is not literally true, of course, that there is no oil in the froth which the appellees produce. If there were no oil in it there would be no froth. The quantity of oil that has been put into the mixture must necessarily be found in the froth. It would manifestly be a physical impossibility to create a froth consisting only of bubbles of air and the particles of mineral. This is admitted in the specifications of the appellees' patent, in which it is said that there must be agitation "until the oleic acid has been brought into efficient contact with all the mineral particles in the pulp," and that the air bubbles which make the scum flotable adhere "only to the mineral particles which are coated with the oleic acid."

It is said in the appellees' brief that one feature of the froth produced by their process is that it is unnecessary to clean the mineral of the oil, as the infinitesimal oil coating had no adhesive effect, and that the concentrates may be freely tabled or vanned, and counsel say: "All you have to do is to gather that froth from these vessels, dry it out, and take it to the smelter." We find no evidence in the record that the froth which the appellees produced may be smelted without removing the oil therefrom, or that it would be a distinct advantage to do so, or that the froth produced by some of the anticipating processes may not be taken to the smelter without removing the oil. If the statement made in the brief is true, it is very clear that that feature of their froth was not known to the patentees at the time of their application for the patent, and is nowhere disclosed in the specifications or claims. The specifications deal only with the production of the scum or froth, but claim 13 includes "filtering off the froth and removing the oleic acid therefrom by treatment with an alkali," and on May 3, 1905, in a statement of their method of oil concentration which they sent to Australia, the patentees said: "The oleic acid is, therefore, of necessity recovered in the process and in the state in which it is required for re-use. This is not undertaken merely for the purpose of recovering the oleic acid, but as a necessary step in rendering the concentrates fit for vanning, separation into blende and galena."

The decision of the court below appears to have been largely influenced by the consideration that the appellees' patent had gone into extensive and successful use. The fact that a patented device or process has gone into extensive and successful use is often of value in determining the question of invention and patentability. It is referred to for the purpose of turning the scales in cases of grave doubt. It is of no value whatever where the question of invention or patentability is free from doubt, and in any case its value depends largely upon the causes which produced it. It is often due to business ability in manufacturing, exploiting and advertising, and to the fact that prior conditions have not stimulated development. The appellees' process, originally patented in Great Britain, has been installed in Australia, Sweden, Finland, Chile, and Wales; and it is in the process of installation in Cuba. It is not improbable that in those countries the prior art may have been substantially unknown, and it is possible that the appellees' success there is referable to the fact alleged in the bill, "that the complainants have been to great trouble and expense in the introduction into use of the process, and have invested large sums of money in its introduction into commercial use in different parts of the world, and in the effort to introduce it into commercial use in the United States." It is in evidence that in making the process known to the public in the United States the appellees have expended $60,187. Notwithstanding these efforts and expenditures, their process has not yet been installed in the United States. In *Olin* v. *Timken*, 155 U. S., 141, 155, it was said: "While the patented article may have been popular and met with large sales, that fact is not important when the invention is without patentable novelty." In *McClain* v. *Ortmayer*, 141 U. S., 419–428, the court said that "the extent to which a patented device has gone into use is an unsafe criterion even of its actual utility is evident from the fact that the general introduction of manufactured articles is as often effected by extensive and advantageous advertising, activity in putting the goods upon the market, and large commissions to dealers, as by the intrinsic merit of the articles themselves."

It would serve no useful purpose to review all the numerous decisions in patent cases that are cited by the appellees. But we will refer to two of them which seem to be especially relied upon—*Naylor et al.* v. *Alsop Process Co.*, 168 Fed., 911, and *United States Mitis Co.* v. *Midvale Steel Co.*, 135 Fed., 103. In the first of these cases the court held that an expert cannot take a process patent which has never been applied industrially and work the process in his laboratory, and discover therefrom something which is not disclosed on the face of the patent, and then transfer that experience back to the time of the patent, and make it a part of the prior art for the purpose of defeating a subsequent patent for a meritorious invention. There is nothing in the present case to which that ruling applies, and it is to be observed that the court sustained the patent in that case expressly upon the ground that the complainant therein was the first to discover a successful process for bleaching flour. The court said: "His act was not selection of known agents in the art of bleaching flour, but was the discovery of the only agent that has yet been found to accomplish that result successfully in the milling industry." The second case is said by counsel for the appellees to be "conclusive." The invention there under consideration was a process for making steel castings homogeneous so as to prevent blow-holes, and it consisted in adding to the molten steel when it is about to be poured into the mould a minute quantity of metallic aluminium. But the distinction between that case and the case at bar is plainly to be seen in the fact that there the inventor made a distinct addition to the known art. He added something which has not been used by others, and which was effective in producing the result which was sought. In the present case nothing has been added.

We hold that to sustain the appellees' patent would be to give to the owners thereof a monopoly of that which others had discovered. What they claim to be the new and useful feature of their invention, as stated by their counsel, is "agitating the mixture to cause the oily-coated mineral to form a froth." As we have seen, that feature was clearly anticipated by the prior art, and when the elements of the appellees' claims are read one by one it will be found that each step in their process is fully described in more than one of the patents of the prior art, with the single exception of the reduced quantity of oil which they use. The patentees of the appellees' patent made a valuable contribution to the art in discovering the smallest quantity of oil which would produce the desired result. In doing so they pursued the course which all skilful metallurgists would be expected to pursue. They made a series of experiments to determine how small a quantity of oil could be used successfully. They found, as all must find who apply the oil flotation process, that certain oils are adapted to use with certain ores, and that a larger quantity of oil is necessary for one kind of an ore than for another. The appellees admit that for some ores they use four times as much oil as for others. Their discovery that a small fraction of one per cent. of oil is sufficient to produce flotation of the metalliferous matter cannot, as we have seen, be made by itself or in a combination the subject of a patent. The appellees cannot take from others the right to use oil economically. This was evidently the ruling of the Patent Office on their application for a patent. One of their claims in the original application was "the process of concentrating powdered ore, which consists in separating minerals from gangue by coating the minerals with oil in water containing a fraction of one per cent. of oil on the ore, and recovering the oil-coated minerals." This was rejected in view of the Cattermole patent "as expressing merely a difference of degree thereover as to the proportion of oily matter employed." Counsel for appellees admit that the claim was properly rejected for the reason that it leaves out the agitation and froth, and say "our invention is something else than the mere reduction of oil."

A careful consideration of the whole patent position inevitably leads to the conclusion that those unexpired flotation patents which contain anything novel contain ideas which are of no commercial value, and that those unexpired patents which describe processes of commercial utility are simply a rehash and revamping and descriptions in detail of the working out of the expired inventions of Haynes, Robson and Crowder, Bradford, Everson, and Froment, and especially of Everson. All the salient points of the flotation method as it is used to-day are accurately described in Everson's patent, and with such clearness and distinctness that anyone of ordinary skill in the treatment of ores can, by following the instructions in Miss Everson's patent, easily produce the results being secured at Broken Hill and elsewhere. That her invention was quiescent for a number of years does not argue any lack of completeness or perfection. The real reason for its lack of commercial application was its startling departure from previous known methods. The only previous authentic case where substances heavier than water had been made to float was the occasion of Elisha's miracle with the axe ; and mining and metallurgical engineers are not great believers in miracles. Her process, therefore, met with ridicule where it needed only ordinary intelligence in the application thereof. Moreover, if the trials at Baker City, Oregon, were made on ore from Eastern Oregon—and they probably were—one can say, without much chance of error, that the first attempt at commercial application was doomed to failure because the ore was not one specially adapted to the process.

CHAPTER IV.

THEORIES.

An entirely unnecessary veil of mystery has been suffered to obscure the theoretical side of flotation processes. The forces involved, it is true, are not of such common cognizance as are those in the older methods of gravity concentration, but they are no more wonderful or mysterious in the one case than in the other. The forces utilized are finite in the range of their manifestations, but we have to appeal to molecular considerations for a complete exposition. The imagination of professional engineers is so well trained in these days that they should have no difficulty in grasping the significance of most of the observed facts, and there is, therefore, no reason why anybody engaged in metallurgical pursuits should not become as familiar with these methods of ore treatment as with any other.

A few analogies may be instanced in order to inspire confidence and allay the well established fear of the mysterious. For example, the amalgamation treatment of gold ores, wherein crushed ore, water, and quicksilver are mixed in proper proportions and in suitable devices, is so well known, and metallurgists have become so familiar with it, that the wonderful and obscure molecular reactions between the gold and the quicksilver are never given any thought. Again, the chemical reactions characterizing the cyanide treatment of gold ores, though we are in a measure able to quantify them by a familiar symbolism, require an undoubted exercise of the imagination by means of a written or mental picture of $KCy + Au = KAuCy$. So in the case of flotation-concentration processes the physical laws are for the most part plain ; and where obscure, the obscurity is not a matter that need obstruct practical application. It is not my purpose to enter into a mathematical or physical discussion of the laws regulating these forces because James Clerk Maxwell, in his classical article on ' Capillary Action ', in the ninth edition of the *Encyclopædia Britannica*, has laid the foundation for a mathematical demonstration of all the phenomena involved ; moreover,

H. Livingstone Sulman and Hugh F. K. Picard have in preparation a full dissertation on the observed facts of surface tension and oleaginous and gas-film adhesion, with special reference to their bearing upon concentration by flotation. Their essay is a document of the highest scientific quality, and we have had a pleasant foretaste of its merit in Sulman's recent announcement of the hysteresis range of the contact angle.

My purpose is to give a description in plain and simple language of what takes place when a particle of mineral floats at the surface of a liquid, leaving the mathematical and molecular aspects of the subject to be discussed at some future time.

Unfortunately, the nomenclature hitherto adopted in discussing the laws and principles governing flotation processes has not been such that it carried any explanation with it, but it is the better part of wisdom not to attempt to introduce new terms. I must confess to an inexplicable dislike of the term, 'surface tension', a dislike that dates from my undergraduate days in the physical laboratory.

SURFACE TENSION.

All masses of substances, whether solid, liquid, and probably gaseous also, have, acting at their surfaces, a force parallel to the surface that is the resultant of molecular activity within the body of the substance, and that tends to resist rupture of the surface. This force, in the case of a liquid, is known as 'surface tension'. It is difficult to measure it, but it has been measured for many liquid substances. For the surface of plain water in contact with air, the magnitude of this force has been determined to be 81 dynes per square centimetre.* In all likelihood the figures will be modified by further experimentation, but for any purpose of the engineer this figure is quite accurate enough.

When a slightly oiled needle floats upon the surface of water, the force that causes it to float is 'surface tension'. This force is strong enough to prevent the needle from rupturing the surface; hence, if the needle cannot rupture the surface, it lies apparently on top of the water, or 'floats'.

As to the nature of the manifestation of energy or force, which we call 'surface tension', the textbooks will give enough to clarify and even confuse, but some attempt must be made here

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***Encyclopædia Britannica*, Vol. v., 11th edition, p. 275.

to render clear what the nature of this force may be. W. R. Ingalls* says: "A body of water, or of any liquid, has greater cohesion in its free surface, *i.e.*, the surface exposed to the air, than elsewhere in its interior, because, whereas the particles in the interior are mutually attracted by adjacent particles in all directions, those which are at the surface have no attractions from the outside—from above, let us say—to counteract the pull from those in the interior." The state of affairs he describes can be illustrated diagrammatically by imagining the molecules of the liquid to be of sufficient size to be represented on paper. In Fig. 5

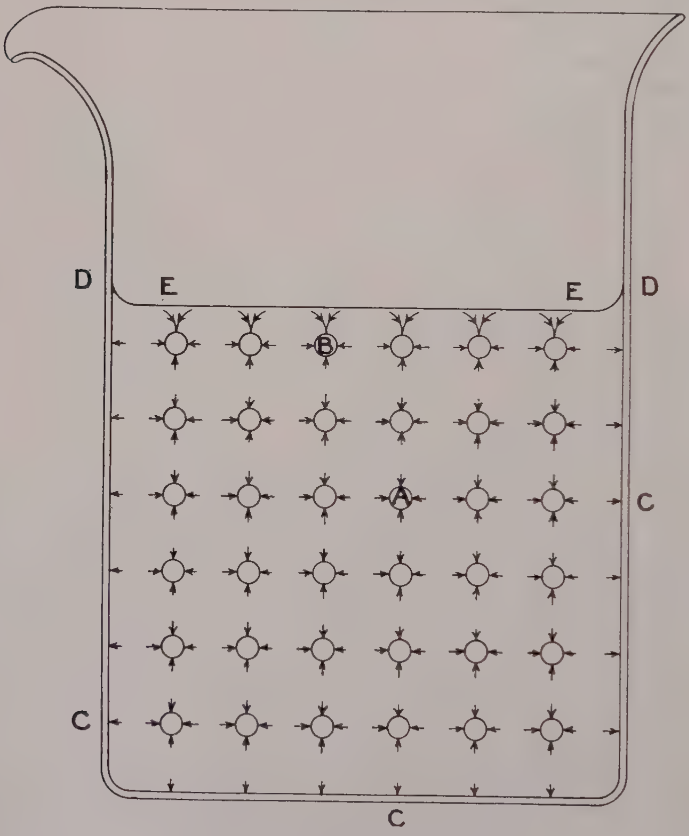

FIG. 5.—Beaker of Liquid.

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*Eng. & Min. Jour., Oct. 26, 1907, p. 765.

each circle will represent a molecule. The molecular attraction of each molecule can be resolved into resultants for purposes of illustration, the resultants being placed as shown by arrows in the figure.* Now the molecule at A, for instance, attracts and is attracted by adjoining molecules by resultant forces that are equal, and the molecule is free to move in all directions. The molecule at B, however, having no molecule above it to attract and be attracted by, is in a somewhat different state from the molecule at A. The molecule at B has its upper one of the six resultant forces uncompensated by a molecule lying above it, so we can assume that this upper resultant is compensated between the molecules on any side of B. This gives the topmost row of molecules a stronger attraction for each other than the molecules adjacent to A have for one another. The attraction of the molecules within the liquid, as, for instance, those at and adjacent to A, is known as the force of cohesion. If this force of cohesion is resolved into the six resultants as above described, and its magnitude is called 6 units, then the magnitude of the molecular attraction acting on a molecule in the top layer, as at B, will be 6 units just the same, but the molecule will not be as free to move in every direction as is the molecule at A. If the stress between any two molecules in the horizontal row containing A is 2, then the stress between any two molecules in the horizontal row containing B will be 2½. Ingalls goes on to say in explanation of this : " The " effect of this is to reduce the mobility of the particles on the " surface. The surface, as it were, is stretched by [like] an elastic " skin, the effect being the same as if the surface layer exerted a " pressure on the interior. The production of this ' surface " tension ' represents energy, *i.e.*, molecular energy which may " be measured." As we have quoted above, from the *Encyclopædia Britannica*, this surface tension has been determined for water to be 81 dynes per square centimetre, a force that resists penetration from within or without the liquid.

ADHESION.

We must go further afield in the study of molecular forces before we can understand clearly the act of the flotation of particles heavier than water, and consider the molecular phenomenon known as 'adhesion'. Referring again to Fig. 5, at C there are molecules that have uncompensated attractions, unless we assume that these are compensated by attraction between the liquid and the solid walls of the vessel. But the force of adhesion is also made up, in part, of the molecular activities of the solid surface molecules, which, we believe, lie much closer together than those of a liquid. The surface activity of a solid would be difficult to measure; but by analogy we are justified in assuming that it is in general greater than the surface activity of a liquid. So that a liquid and a solid in contact should have an attraction for each other in general stronger than the surface tension of the liquid. This state of unbalanced liquid stresses at the bounding surfaces of a liquid also gives rise to a further noticeable condition, as at D, where the corner molecule has not only its upward component, but also one of its lateral components near E abnormally compensated. This will give an illustration of what produces the meniscus, where a liquid, a solid, and a gas come into contact. Adhesion is not, however, limited to solids on liquids, but acts in solid-gas, and probably gas-liquid couples. The mathematics of these forces and the theoretical discussion could be pursued considerably further, but enough has been given to illustrate the terms employed.

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*To make the assumption complete we must imagine two resultants acting at the centre of each circle, at right angles to the plane of the drawing.

The films of gases that are attracted to the surfaces of solid particles adhere strongly in some instances, and are displaced therefrom by a liquid with considerable difficulty. This quality of adhesion varies remarkably with different substances.

With some substances the gas adhesion is strong and the liquid adhesion is weak; in other words, they are wetted with difficulty. In this class are the metallic sulphides, which, although they have a natural tendency not to adhere strongly to water, fortunately do have a strong natural tendency to adhere to oil. And further, oil has an even stronger tendency to adhere to its gas film, so that a sulphide particle, when touched with an oil film, has considerably increased an already strong tendency not to adhere to water. Quartz and gangue minerals generally, on the other hand, have preference in directly the opposite direction. They have a comparatively feeble adhesiveness to gas films and oil, and a strong adhesiveness to water, and this already strong adhesiveness for water is greatly increased by a slight acidulation of the water. There has been no satisfactory theory yet propounded as to why acid does promote the preferential adhesion of water to gangue particles, and probably also increases at the same time the preferential adhesion of oil to sulphides, and for the present commercial purpose it does not seem necessary to do more than record this important fact. Bertram Blount, in speaking of sulphide particles, has expressed the idea of selection or preferential oiling as follows: "Before they were oiled at all their surfaces had certain qualities, one of which is a tendency not easily to be touched by and wetted with water. On the other hand, correlated with that property is the power of being easily touched by and wetted by oil. When they were put through this process they exercised both properties, and acquired or annexed a minute quantity of oil, which was presented indifferently to them and to the gangue, only they obtained it and the gangue did not. They came out of the process with that inherent quality enhanced by a minute film of oil, and then they were even less ready to be wetted by water and to sink through it than they were before, but it was only an exaggeration of what was a native quality."* Kenneth A. Mickle, in an excellent paper,† giving the results of experimental work on gas-bubble and oil attachment, points out that gas-bubble adhesion does not take place if the amount of oil is too large—that is, if the sulphide particles are too much wetted by oil. His paper is the most valuable contribution that has yet appeared on these subjects; but, unfortunately, he has used both the words 'cohesion' and 'adsorption' where he should have used 'adhesion'.

Thus it has been established that there are:

(1.) Forces acting at the surface of a liquid, the resultant of which tends to prevent rupture of the surface.

(2.) Forces acting at the surfaces of all substances, and especially at the surfaces of sulphide particles, that cause films of gases resisting displacement to adhere to their surfaces.

(3.) Forces acting at the surfaces of sulphides that cause these surfaces to show a preferential adhesion to oil.

(4.) Forces acting at the surfaces of gangue minerals that cause these surfaces to show a preferential adhesion to water, and especially acidified water.

We now have the main principles by which to account for the 'floating' of particles heavier than water, and we shall not worry as to what more these forces are, nor discuss the mathe-

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*Evidence at trial of B.O.C.S., Ltd., *v.* M.S., Ltd., 1908.

†*Australian Mining Standard*, Vol. XLVII., 1912, pp. 333, 357, 381 & 403.

matical formulæ by which they can be resolved into their component parts.

In the simplest case we have a small particle of zinc sulphide, which has been exposed to the air, and upon the surface of which there is adhering a film of air. This particle of blende P, Fig. 6, is then brought into contact with water. The force of adhesion between the particle and the film of air prevents the water from displacing the film of air, and the force of surface tension prevents the particle of blende from penetrating the water surface; therefore the particle is suspended at the surface thus:

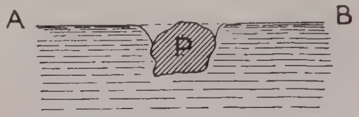

FIG. 6.—Floating Piece of Mineral.

If this particle of blende, P, before being brought into contact with the water, had been touched with a thin film of oil, and if the water had been slightly acidified, then both the adhesiveness of the particle for the gas film and the resistance of the liquid surface to rupture would have been increased, and the act of 'floating' would have been made triply sure by the natural tendency of the blende and the enhancing action of the oil and acid. If at the same time a particle of quartz gangue had been brought into contact with the acidified water surface, it would have behaved in an entirely different manner. The particle of quartz, having a much feebler adhesiveness for its air film, and having a strong natural tendency to adhere to water, and also having this tendency to adhere to water and become wetted with water increased manifold by the acidulation of the water, it would have quickly penetrated the liquid surface and sunk to the bottom, for the act of wetting implies at the outset penetration of the surface.

BUBBLES.

In Fig. 6 it should be pointed out that the surface A B may be either the horizontal surface of a liquid at rest (and considered the limiting surface of a bubble of infinite radius), or, equally important, the surface A B may be considered the surface of a bubble of small diameter within the body of a liquid. This bubble may have a radius of one foot or one inch or one thousandth of an inch, and the action of the sulphide particles with reference to the bubble will be just the same as it is with reference to the free surface of a liquid. If the bubble has a radius of, say, one-tenth of an inch, and the blende particle a mean diameter considerably less, the bubble will rise by its buoyancy to the surface of the liquid, and carry up with it the blende particle adhering to the surface A B of the bubble. If then, instead of only one blende particle, we mix slightly acidified water with crushed ore and a little oil, and release in the whole body of the pulp a large number of minute gas bubbles, we shall have the above described sequence of events taking place in innumerable instances, and these innumerable bubbles will rise to the surface of the liquid and rest there in the form of a froth, carrying with them the sulphide particles, while the gangue in the meantime has exercised its preferential adhesion for the water and become wetted, and remains within the body of the liquid and sinks to the bottom of the vessel. The bubbles may be bubbles of air introduced by violent agitation of the pulp, or air bubbles released from solution in the liquid by subjecting the liquid to a vacuum, or air bubbles dissolved in the liquid at super-atmospheric pressure, followed by a release of pressure; or they may be carbonic-acid gas bubbles released by the chemical reaction of sulphuric acid on carbonates, or in several other ways.

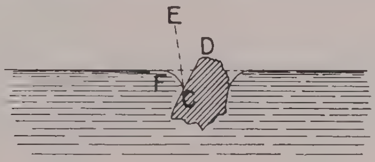

Fig. 7.—The Contact Angle.

In Fig. 7 it will be seen that near C there is a point where the air, the liquid, and the solid all meet in a common point, this point being the trace of a line perpendicular to the plane of the drawing. The angle E C D is made up on one side with the solid and the other side with a tangent drawn somewhere on the curve C F. It is certain that a study of the curve C F, by means of a microscope and screen, would be a profitable line of experimental work. Maxwell says: "The constancy of the angle of contact between the surface of a fluid and a solid was first pointed out by Dr. Young." It is difficult to say where this tangent should be drawn. From a consideration of the forces acting near the region of mutual contact between a solid, a liquid, and a gas, it seems most reasonable to assume that there is no definite point where one could draw a tangent, but that the curve C F is a continuous curve, the functions of which are: (1) The force of surface tension of the liquid; (2) the force of surface activity or adhesiveness between the solid and the liquid; (3) the force of adhesiveness between the solid and the gas; (4) the force of adhesiveness between the gas and the liquid; (5) the force of gravity; (6) temperature; (7) pressure; (8) shape of the solid surface; (9) composition of the solid; (10) composition of the liquid; (11) composition of the gas; and others.

The methods of measuring what are termed contact angles are shown in Fig. 8, a piece of mineral having one plane surface, generally a cleavage plane, being immersed in a liquid surface as at A, and then turned through an angle, α, to a position like B. As the piece of mineral turns, the curved surface of the liquid in the neighbourhood of the line of mutual solid-liquid-gas contact flattens until it is horizontal, and the angle $180^\circ - \alpha$ is said to be the angle of the contact. This angle is a definite angle under fixed conditions.

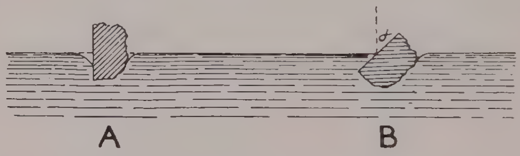

FIG. 8.—Measuring Contact Angle.

H. Livingstone Sulman, in Bulletin No. 79, Trans. I.M. & M., speaking of the angle $180^\circ - \alpha$, announced that "a study of a series of observations on various substances showed a series of curiously discrepant readings, which on further research proved to be due to the existence of a variable range of the contact angle between liquids and solids, though of constant magnitude of variation for each substance. This hysteresis appears to be intimately connected with the ability of a given solid to condense upon itself gas films, and when submerged in a liquid to determine the attachment of a gas when generated. It follows that this angular hysteresis reaches its highest value for minerals that are the most susceptible of flotation. Besides roughly quantifying the gas-condensing power due to the surface energy of solids, we are brought somewhat closer to an explanation of the efficiency of acidification. Whereas the angular hysteresis of silica in plain water may exceed 30°, thus indicating that substance to have a definite power to occlude gas and float, it drops to from 4° to 0° in water acidulated with sulphuric acid." Sulman has here announced a discovery of the first magnitude, and places in the hands of the physicist a clue to many puzzling questions.

COMMERCIAL EFFECTIVENESS.

The forces with which we are dealing are feeble in magnitude when compared with, say, the force of gravitation. It should be emphasized, however, that although these forces acting at the surface of substances are to our conception feeble, they act continuously at all surfaces; and although we cannot increase the unit force, we do have it in our power to increase enormously the units of surface, and thereby we can bring the nett resultant work of these forces up to an effective sum.

There are two ways in which the surfaces involved can be increased. A cube of ore 2.1544 feet on each edge contains 10 cubic feet. If this ore is a definite mixture of quartz, blende, galena, etc., it will weigh just a ton. The cube will have a total surface area of about 28 square feet, or roughly 4,000 square inches. If this cube of ore is crushed to 40-mesh it is certain, on reasonable assumptions, that the superficial area of the ton of ore is increased to more than 30,000,000 square inches, an increase in area of several thousand times the original.

The De Bavay process uses the surface film of the liquid at rest as the transporting agent, and therefore does not get the advantage of the second method of increasing the surface factor, which is advantageously made use of by Elmore, Minerals Separation, and Potter-Delprat. This second method of increasing the effective surface is by creating a froth of bubbles, each bubble of which acts as previously described. It is no unusual sight to see on the flotation boxes of the Potter-Delprat and Minerals Separation processes two inches of froth composed of a compact arrangement of bubbles and sulphides. By determining, roughly, the size of the bubbles and the distance apart, it is safe to say that the available liquid surface is increased from 20 square feet on the free surface of the liquid in a box to 2,000 square feet when the surface of all the bubbles is counted. In the case of both the mineral and the liquid it is obvious that only a small portion of the surface is used for the work of flotation.

As before stated, the surface tension of water has been determined to be a force of 81 dynes per square centimetre, acting at the surface, to resist penetration of the surface. If we assume that the force tending to make finely divided sulphides penetrate the surface is the force of gravity, then each gramme of sulphides is impelled to penetrate the surface by a force of 981 dynes, and therefore one square centimetre of the surface will hold up 81 ÷ 981 = 82.6 milligrammes of ore.

Leaving out of account the enhancement of this force of surface tension by the admixture of oil and acid and other means, the following table will show that this force is adequate for the work required of it. The efficiency of the utilisation of the force is in all four cases very low :—

	No. of Machines.	Feet of overflow lip.	Sq. feet of Surface.	Times per min.	Capacity at (81 dynes per sq. cm. = 82.6 mg. per cm.) lb. per hr.	Actual lb. produced per hour.	Actual lb. per hour per ft. of lip.	Actual lb. per hr. per sq. ft. of surface.	Theoretical Capacity lb. per sq. ft. per hour.
De Bavay	88	2765	1620	20	328,800	44,800	16	28	202
Elmore	10	45	6.5	60	3,960	8,064	179	1,240	609
Minerals Separation	6	24	120	3	3,650	31,360	1,300	260	30
Potter-Delprat	3	14	68	3	2,065	26,880	5,376	395	30

Referring to the last two columns, in the case of Minerals Separation, Elmore, and Potter-Delprat, it will be seen that they have increased their theoretical capacity per hour, based on the surface area of the boxes, to several times more actual working capacity by means of making a froth. The variables in the problem are so many that it is not safe to attempt more than to quantify roughly the force available, but it is certain that the force available is many times as large as is necessary for the work to be done. This phase of the subject is an interesting one for research and speculation, and will, no doubt, receive critical study.

SOLUBLE FROTHING AGENTS.

In what has been said before in regard to the production of a mineral froth and the promotion of mineral flotation, I have had in mind the use of some insoluble substance like oil or grease. In the Potter-Delprat process a froth is presumably produced without any oil, but in that case carbonic acid gas is the gas used. It is a significant fact that no method has yet been found of producing a mineral froth by air bubbles without the addition of oil or some other substance. In addition to the above there are a number of soluble substances that will assist in producing a commercially effective mineral froth such as amyl alcohol, camphor, most of the essential oils, the phenols, and a number of gas-tar derivatives.

The phenomena to be observed in connection with the use of these soluble substances as mineral frothing agents are confusing. What has been said about the oil adhering to the sulphides in the first part of this chapter does not apply in the case of these substances, because they are completely soluble in the proportions used; being completely soluble in the proportions used, the small amount employed in treating the ore (1 lb. per ton of ore) cannot be thought to adhere preferentially to the sulphides. On the other hand, although these substances are soluble, the solution cannot be used over and over again beyond narrow limits, but the frothing agent must be added continuously. The reagent is probably volatilized at the temperature used and is so dissapted. It is also inconceivable that there is any chemical reaction between, say, the soluble essential oil of *eucalyptus amygdalena* and any of the ingredients of the ore. The froth produced in this case has identically the same appearance as where air, oil, and acid, or acid and carbon dioxide, are the froth constituents, and we are justified in assuming that in the main there is no difference in the forces acting. A complete answer as to just 'What is a froth?' would probably clear away all the uncertainty as to just 'What is a flotation process?'

COAGULATION.

One of the most significant facts to be observed in these processes is the coagulation effect of the operation. As an illustration: when a little salt or acid of almost any kind is added to soapy water, the soap collects in flocculent masses; we say the soap has coagulated. So in this ore-treatment operation it will be observed that the sulphides are coagulated in masses, some of which are of appreciable size even when they have not gathered sufficient air bubbles to float them. The gangue, on the other hand, has not coagulated; but, due to the fact that the sulphides have coagulated, the gangue assumes an appreciably different and generally lighter colour than was the original ore. If the sulphides have not been floated as a froth (due to insufficient gasification), it will be observed that the ore as it settles has a streaky or mottled appearance, due to the fact that the darker sulphides have coalesced in considerable masses. It is not to be inferred that coagulation is a condition necessarily precedent to successful flotation, for it is not; but in tests, and in the operation of a working plant, coagulation is a 'sign of good work'.

R. Storm says: "Fine slime cannot be treated by these processes because, as the volume and area of the particles approach zero, they will have no adhesion effect." This is just where coagulation becomes a factor in rescuing the slime, and, contrary to his opinion, it is the fact that adhesion does act, and that coagulation is simply one of the manifestations of adhesion. By a process that gives violent agitation with aeration and warming, the slimed sulphides coalesce together in the form of coagules, and then become, if they were not before, amenable to the forces of gas-adhesion and surface tension.

This coagulation of the sulphides is similar to the process of butter making, where, after a period of agitation of the cream, the butter-fat particles in the cream begin to adhere together, and finally grow into balls of butter of appreciable size, and the dairyman says: "The butter has come." So in the case of an ore-pulp with a small portion of oil added, with or without acid, if it is stirred for a suitable length of time with a rolling motion, the sulphide particles begin to adhere together, and if the rolling motion is sufficiently prolonged, the sulphides can be made to gather together into balls an inch in diameter free from any gangue particles. If this coagulation effect is stopped in its incipient stages, and if a multitude of infinitesimally small gas-bubbles are released in the pulp, each bubble lays hold of a 'coagule' of sulphides and buoys it to the surface where the mixed bubbles and sulphides rest in the form of what we call 'froth.'

CHAPTER V.

TESTS.

From what will be said later in regard to the limited applicability of these methods, it will be evident that anyone undertaking the study for the first time of either the application of the processes to a particular ore, or the theory of the processes themselves, should begin with an ore that is easily treated by flotation. What is needed is an ore that presents the fewest special problems. An ideal mixture for the experimental work of a beginner would be one composed of 60% quartz and 40% brown blende, or say, 70% quartz and 30% of pyrite or chalcopyrite. These mixtures are not common in nature, but approximations thereto occur frequently. With the above proportions in mind as ideal ores for the beginner, it is well to ascertain that the ore chosen does not contain more than 2.5% of calcium carbonate or other carbonates. A series of experiments for the beginner who has had no previous knowledge of the processes can easily be made without special apparatus, and such experiments will serve to illustrate some of the phenomena of concentration by floating part of an ore at the surface of a liquid. At the very outset a standard test should be selected for trying each new ore studied or each new oil investigated. The behaviour of the new material under these standard conditions can then be compared with previous results, thus giving the investigator a point of departure in his explorations. A good standard experiment is 1,000 parts of ore crushed to 60-mesh, 3,000 parts of water, 10 parts of sulphuric acid, and 1 part of oil, all by weight and at a temperature of 70° C. Variations can then be made from these proportions in conformity with the special characteristics of each ore under examination, or the special nature of the oil used, or of any other variable that may be under examination. In beginning the investigation of any ore, the above is a good combination with which to start the first experiment, and then the proportions may be varied by gradual steps until the combination giving the maximum result is reached.

In the following experiments the ore can be weighed in an ordinary balance; the water can be measured in cubic centimetres, calling 1 cc. a gramme; the acid can be measured from a burette, but the oil should be measured by counting drops from a glass tube drawn to a medium fine point, previously having determined by trial how many drops of a given oil go to make up one-tenth and one-hundredth of a gramme, because the preliminary experiments will be with small amounts of materials.

EXPERIMENT 1.

Take	10	grammes of	ore.
	30	,,	water.
	0.1	,,	sulphuric acid.
	0.01	,,	oleic acid.

Temperature 75° C.

Place these in a test-tube of 75 to 100 cc. capacity; warm contents to about 75° C; close the tube with the thumb, and shake energetically for about a quarter of a minute. The only measure that can be cited for the amount of shaking necessary is to shake the tube until the arm aches. Upon allowing the tube to stand a few seconds there should be decided indications of a separation into layers. At the bottom should be a layer of quartz or gangue much lighter in colour than the original ore; then a layer of gradually settling gangue-slime; then a thin layer, gradually increasing, of sulphides dropping through the liquid; then a considerable layer of dirty water; and finally, on top of all, a layer of froth composed of bubbles of air and sulphide particles. By varying the amounts of oil or other ingredient of the mixture a series can be secured for comparative inspection. Some of the froths made with certain oils are of wonderful persistence, and if undisturbed will stand without alteration for months.

The next step is to take a larger vessel, say, a wide-mouthed bottle holding 200 cc., one that can be grasped comfortably by both hands and held in front of the operator with the thumbs over the cork. The shaking must also proceed to the aching point by the energetic use of the arms and shoulders. The charge in a series of tests of this kind will be:

Ore (60-mesh)	30	grammes.
Water	90	,,
Sulphuric acid	0.3	,,
Oil	0.03	,,

Temperature 75° C.

Shake and allow to settle. By carefully preparing a set of bottles for comparison, or by familiarity with a long range of similar tests, the operator can by inspection make a rough estimate as to the result. In the case of both the test-tube and the bottle it is difficult, if not impossible, to get quantitative results.

The question of securing, on a small scale, quantitative results that would bear some known relation to actual milling operations, and at the same time be under ready control as to the various factors, has occupied considerable attention. Small machines built exactly like large machines do not always duplicate the large-scale operations. Perhaps the best all-round apparatus for a study of ores and the influence of oils, acids, temperatures, etc., on surface tension results is a small machine,* suggested originally by the author to H. L. Sulman and John Ballot, first made by H. F. K. Picard, and improved to its present form by James M. Hyde and others of the Minerals Separation, Ltd., staff, as illustrated in the accompanying photograph. The driving mechanism to the left of the picture does not require any description, and can with advantage be discarded in favour of a small motor. The motor also

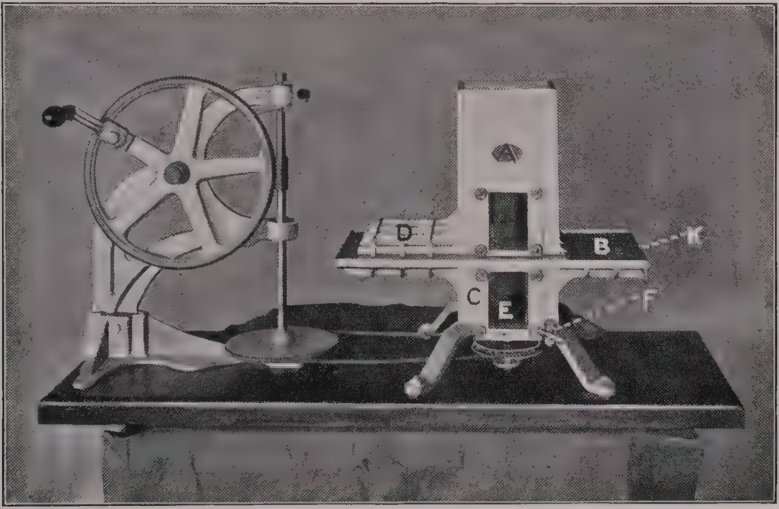

FIG. 9.—Slide Test Machine.

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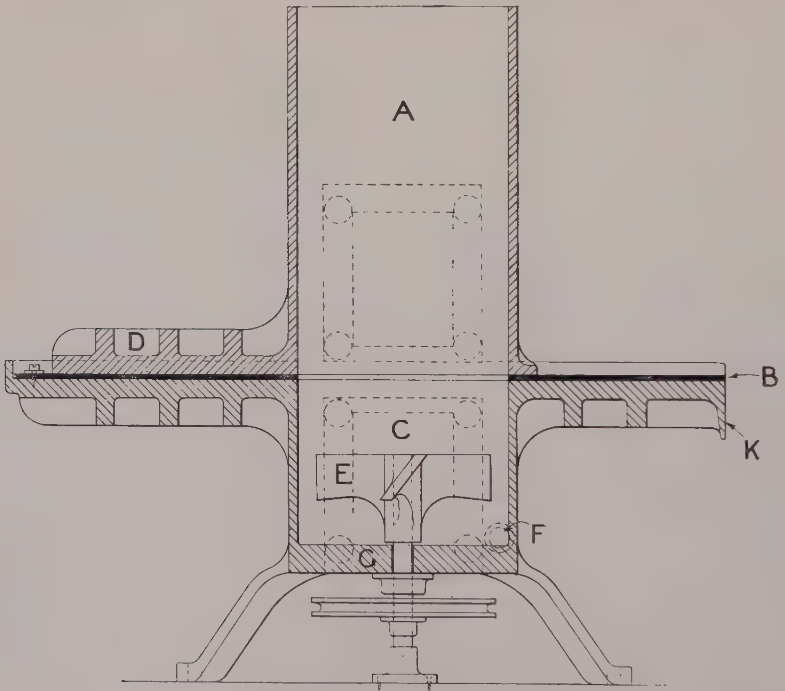
*This machine is not patented.

has the advantage that exact speeds can be duplicated, as well as exact lengths of time of agitation. The portion of the apparatus on the right can be better described by reference to Fig. 10, which is a section drawn through the apparatus parallel to the plane of the photograph. Fig. 11 is a transverse section, and Fig. 12 a plan of the machine.

This machine is made in two parts, an upper one A, and a lower one C, both sliding easily on a rubber cushion B between the two parts, or, better still, having the bearing surfaces highly polished. The rectangular section of the interior is 4½ inches. The upper part



LONGITUDINAL SECTION.

FIG. 10.—Machine for Tests.—Scale on next Page.

A has a tail D, the purpose of this being to prevent leakage of the froth when the upper part is slid to the right for the purpose of removing the froth. Windows of glass in each of the two parts enable the operator to watch the progress of the test. At E there is a simple agitator with four arms at right angles. The shaft driving this agitator goes through the bottom G of the lower part C,

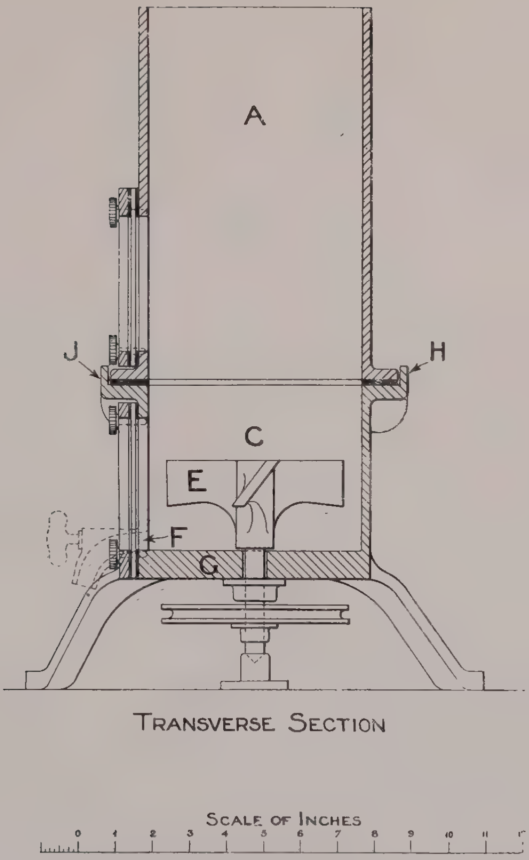


FIG. 11.—Machine for Tests.

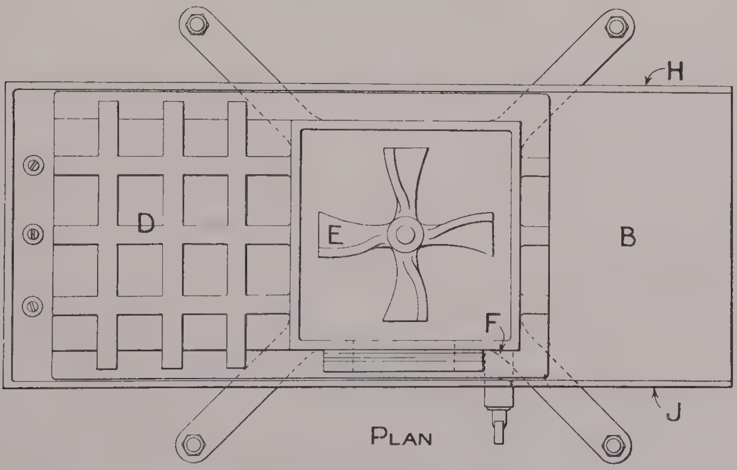


FIG. 12.—Machine for Tests.

and is packed with a small stuffing-gland to prevent leakage. At F is a hole communicating with the interior at the bottom, closed with a valve. This hole is for the withdrawal of tailing. The agitator-arms are 2 inches long from the centre of the shaft, thus describing a circle of 4 ins. when revolving, and so leaving a clear space, ¼ in. wide, between the ends of the arms and the sides of the interior. The normal speed of this agitator is about 1,500 r.p.m. The machine should be made of some metal that gives a clear casting. The lower surface of A, which rests on the rubber cushion B, and the upper surface of C, upon which the rubber cushion rests, should be planed and polished smooth. The cushion is a piece of rubber insertion about one-sixteenth of an inch thick, and just wide enough to fill the space between the edges H and J of the tray-like top of C. The cushion can be discarded if the surfaces are accurately planed and polished.

The equipment necessary for the tests will also include a tin boiler, with the proper connections to make steam at a low pressure, the steam being introduced by a tube hanging from the top of the machine almost to the agitator inside. An assortment of agate-ware dishes, burettes, pipettes, etc., is an obvious necessity. Having arranged everything in order, the method of making a test is as follows: Measure 1,500 cc. water and place in the machine. This will fill it to about ½ inch above the bottom of the upper window. There will be no leak at the plane of junction between the upper part A and the lower part C, because the planed surfaces adhere to the rubber sufficiently to prevent leakage under the slight head. Start the agitator at half-speed, and then admit the steam. While the agitator is running, steam in large volume can be admitted without any 'bumping.'* Weigh 500 grammes of properly crushed ore, and put it into the agitating water; test the temperature, and when it is at 75° C add the oil and acid in such quantity as the test requires. Turn on the motor to full speed, and let it run, say, five minutes. Stop the motor and agitator, and let the whole experiment set for one half-minute to allow time for the froth to collect on the surface of the water and for the gangue to settle. If the experiment is a success, the gangue will be much lighter in colour than was the original ore, and will mostly settle to the bottom of the machine, where it can be seen through the lower window. Immediately above the heaviest sandy gangue will be seen the finer gangue and slime rapidly settling. At the bottom of the upper window will be a gradually increasing layer of nearly clean water, and on the surface of the water will be from ½ to 1¾ inches of a dense sulphide froth, the amount of froth depending on the proportion of sulphides in the ore and the success with which the experiment is conducted.

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*This machine can be cast with a heating-chamber around the lower section, thus enabling heat to be applied by a gas-burner and obviating the necessity for steam.

The purpose of the peculiar construction of the apparatus will then be apparent, for the upper part A can be slid along the cushion B, carrying with it the froth and that portion of the clean water above the plane of junction of the two parts. When the upper part has been slid to a position where the screws in the right-hand side of the upper window are directly over the lip K, the froth and clear water will run out into a dish placed under K. The tailing, slime, and remaining water can be given a further agitation, but enough water should be added to bring the water up to a line above the bottom of the upper window. After the second period of agitation, a further amount of froth will be formed; this can be removed in a similar manner, and a third and fourth also, if desired. After all the froth has been secured, the tailing, slime, and remaining water can be removed at F, and the two products, concentrate and residue, examined for weight, size, or composition. In this machine an average of 20 tests per day

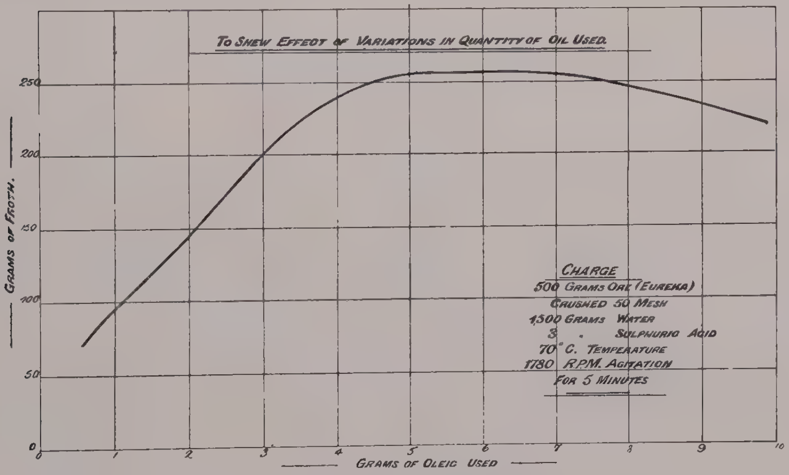

FIG. 13.—Quantity of Oil.

can be made, and the following series is suggested as instructive:

Take 100 lb. of ore crushed to 60-mesh, such as described above as being suitable: mix thoroughly and put in a dry place for use in the whole series of experiments.

SERIES A.

No. 1.—	Ore	500 gm.
	Water	1,500 ,,
	Acid	5 ,,
	*Oil (oleic acid) ..	0.1 ,,

Temperature 80° F.
Agitate at 1,800 r.p.m. for five minutes.
Allow to settle for five minutes.
Remove froth, filter dry, and weigh and assay if desired.

2. Same as No. 1 except 0.2 gm. oleic acid.
3. ,, ,, 0.3 ,, ,,
4. ,, ,, 0.4 ,, ,,
5. ,, ,, 0.5 ,, ,,
6. ,, ,, 0.6 ,, ,,
7. ,, ,, 0.7 ,, ,,
8. ,, ,, 0.8 ,, ,,
9. ,, ,, 0.9 ,, ,,
10. ,, ,, 1.0 ,, ,,

A useful series of observations can be secured by simply observing the weights of concentrate produced. More interesting data, however, can be obtained by sizing both the tailing and the concentrate on a standard series of screens and then assaying the sizes. When the results are plotted from the weights of the various concentrates secured in this series, the curve will be of the nature of Fig. 13. This curve shows that for this ore under these conditions the maximum effect is secured with 0.5—0.8 gramme of oil. More than that amount is detrimental, which fact would be proved by still further increasing the amount.

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*Oleic acid is an oil by-product from tallow candle manufacture, which can be secured almost anywhere.

SERIES B.

No. 1. Same as Series A, except oleic acid 0.5 gm. and sulphuric acid 0 gm.
2. Same as No. 1, except sulphuric acid 0.5 gm.
3. ,, ,, ,, ,, 1.0 ,,
4. ,, ,, ,, ,, 1.5 ,,
5. ,, ,, ,, ,, 2.0 ,,
6. ,, ,, ,, ,, 2.5 ,,
7. ,, ,, ,, ,, 3.0 ,,
8. ,, ,, ,, ,, 3.5 ,,
9. ,, ,, ,, ,, 4.0 ,,
10. ,, ,, ,, ,, 4.5 ,,

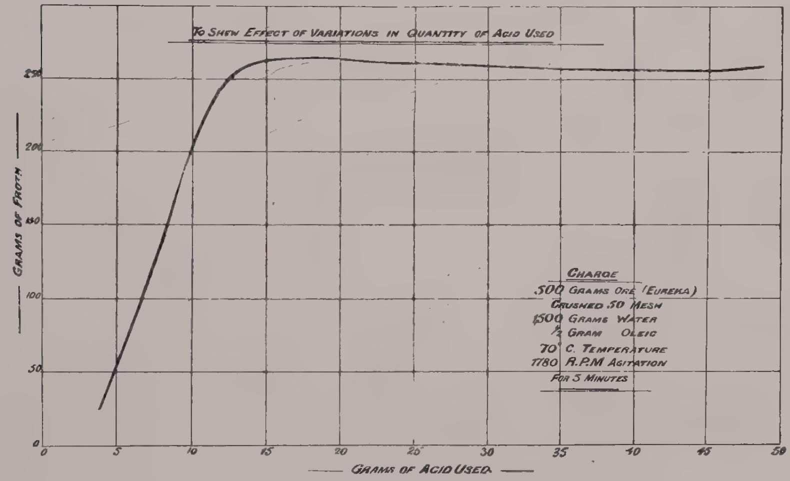


FIG. 14.—Quantity of Acid.

According to the amount of carbonate in the ore, the curve of the plotted results will be something like Fig. 14. This ore needs but little acid, the maximum result being secured with 13 grammes. It will probably be ascertained that if the acid is increased sufficiently the recovery is less, because a point is reached where H_2S gas begins to be evolved, and this gas is generally fatal to flotation.

Other series can be built upon the two illustrations already given by varying at regular intervals the temperature, the proportions of ore and water, the nature of the oil, the length of time of agitation, and the speed of agitation. Then having exhausted the

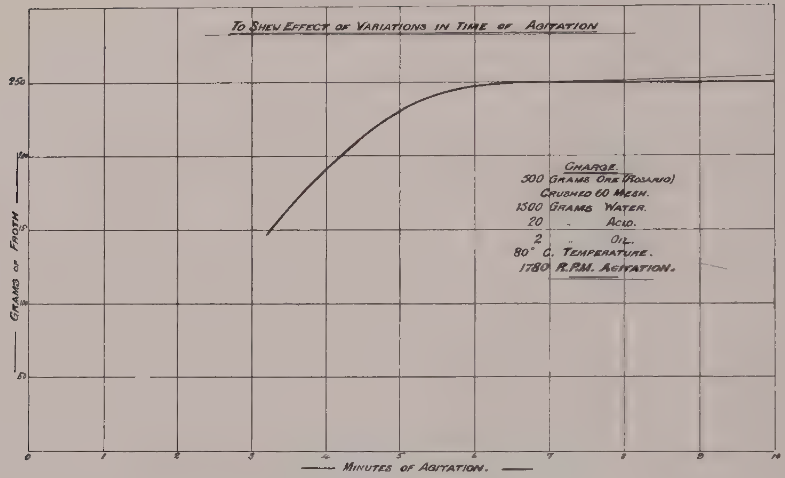


FIG. 15.—Time of Agitation.

possibilities of variation using oleic acid, start a series with a different oil, say, the soluble essential oil of *eucalyptus amygdalena.*

Fig. 15 shows the effect of variations in time of agitation.
Fig. 16 " " " speed " "
Fig. 17 " " " temperature.
Fig. 18 " " " time of agitation with various oils, and also recoveries with various oils.

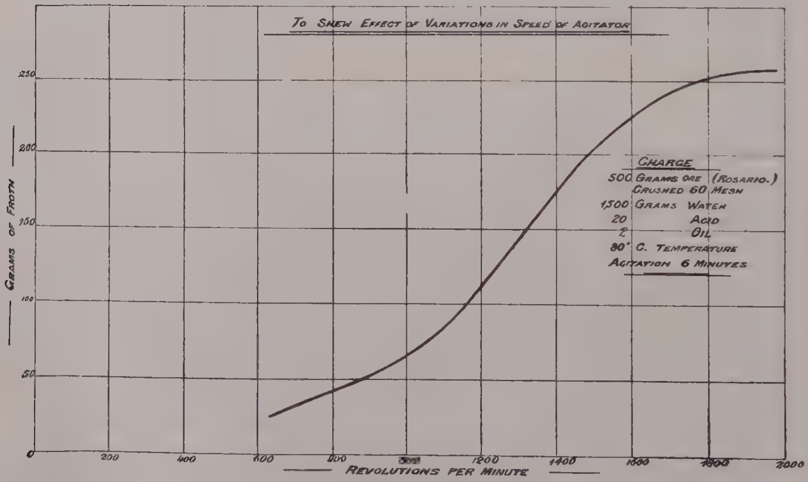


FIG. 16.—Speed of Agitation.

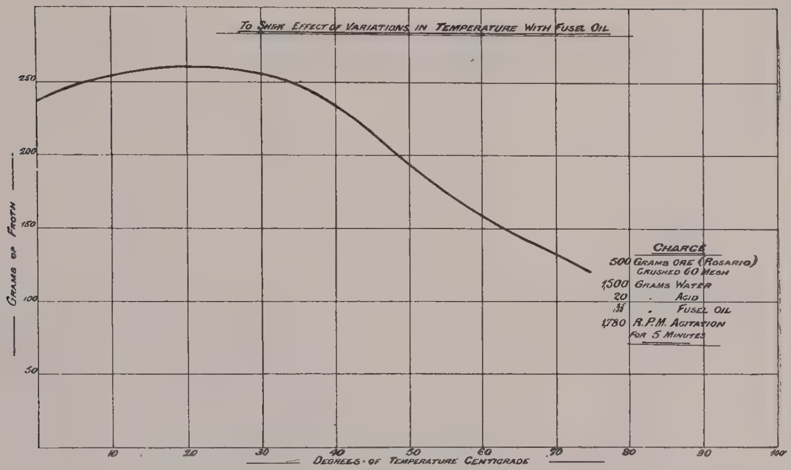


FIG. 17.—Temperature.

The above series of tests, it will be observed, is by means of a process that includes the use of oil and acid and the addition of air by violent agitation. The general principles are the same as in any other combination, and as they are easily applied and approach working conditions, and the results are comparable with those secured in large plants, they are of considerable value. Over a period of four years, when thousands of small tests were made on

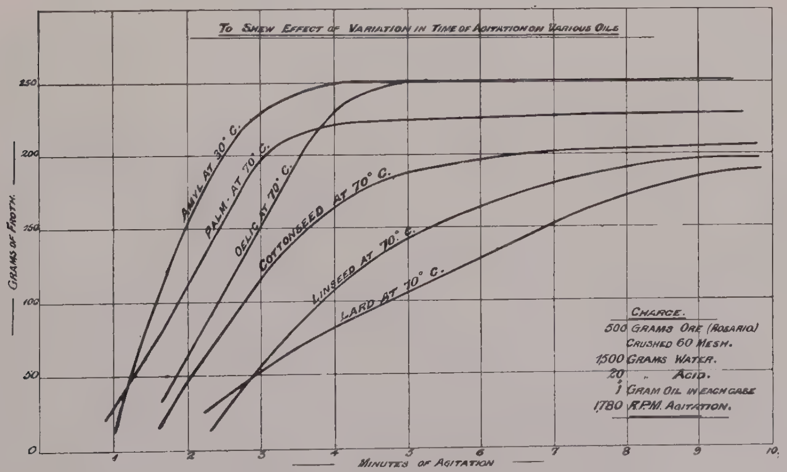


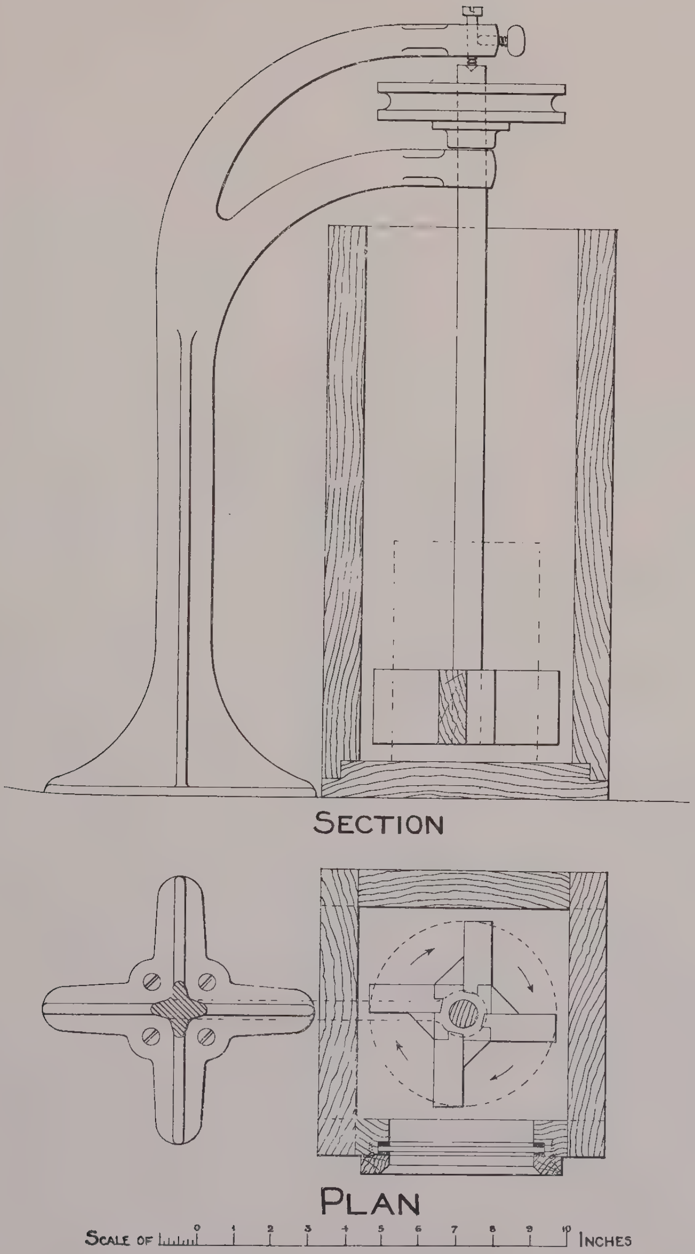
FIG. 18.—Various Oils.

an ore that was being treated in two plants of 1,000 tons per day, the results from the small tests averaged 5% less recovery and 3% lower-grade zinc in the various concentrates than were secured in the large plant.

This machine is a useful addition to the ore-testing laboratory, whether flotation processes are in view or not, because, by the use of it and the expenditure of sufficient acid and agitation, the sulphide contents of almost any ore can be determined accurately.

Another machine of simpler design and cheaper construction is shown in section in Fig. 19, and in plan in Fig. 20. It is made of easily procurable materials, and can be constructed in the laboratory. It has the disadvantage, however, that it requires some skill in removing froth after the agitation. The froth can be removed by careful skimming with a spoon. Some froth will unavoidably be sunk during the skimming operation, but the agitator can be started again, followed by a second skimming. If there appears to be still further chance of a useful result, a third and fourth period of agitation and skimming can be tried. If this machine is made 4½ inches square, inside measurement, and 10 inches deep, it will be the right size for tests on 500 grammes of ore. The equipment necessary for making tests will also include a tin boiler, with the necessary connections for introducing steam into the apparatus. The agitator should be so belted to the motor that it will run about 1,500 r.p.m. The agitator should be about 4 inches in diameter, thus leaving ¼ inch clear all round its path of rotation. The method of conducting a test will be just the same with this machine as with the other, except in the matter of removing the froth, and in this instance it will have to be removed by an ingenious hand. Carefully skim as much as possible of this froth off the surface of the water with a large spoon. The design and material of this spoon can be left to the ingenuity of the experimenter, as each man will fancy one of his own invention. Some froth, as said before, will be sunk during the skimming operation, but the agitator can be started and run for one minute previous to another skimming. A third and a fourth, if necessary, will give a fair recovery, provided good mineral-frothing conditions have been established. This machine will yield much instruction, but is not as direct in its results as the one in Fig. 6.

An interesting series of experiments can also be conducted in an ordinary soda-water syphon. The cap of the bottle should be altered so that the pressure can be raised in the bottle with a bicycle



FIGS. 19 AND 20.—Apparatus for Tests.

pump. The necessary alterations are quite easily done, and can be effected in the laboratory. The charge will be 100 grammes of ore, 300 gm. water, with acid and oil to suit. The air-pump should be one with a pressure-gauge attached, so that pressures can be noted. After pumping to 30 lb. pressure, the bottle with the charge should be shaken a few times, so that the air will dissolve. Then the lever being depressed, most of the charge can be drawn into a beaker, and the froth and tailing examined at will. It is worth noting in this connection that excellent mineral froths can be made at normal atmospheric temperature.

ANOTHER LABORATORY TESTING MACHINE.

Since the publication of the first edition of this book another machine has been thoroughly tried in the laboratory of the author

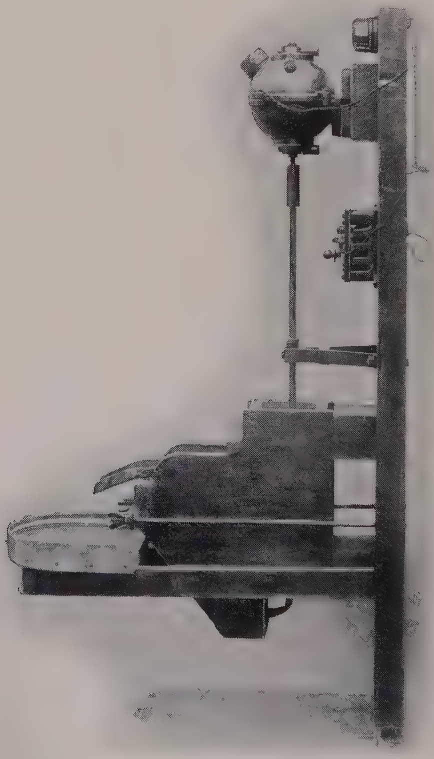


FIG. X.

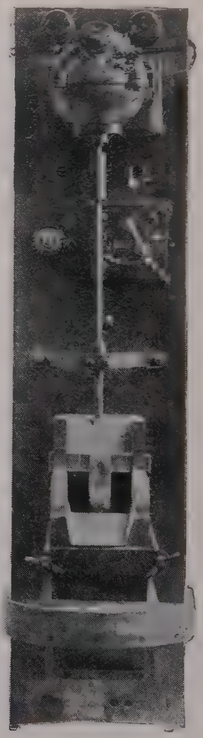


FIG. Y.

and the results are much superior to those previously described in this chapter. Two photographs of this machine are given herewith (Figs. X and Y), and a side view is also shown in Fig. Z. The latter is taken from Lyster's patent. The apparatus comprises an agitating or mixing vessel N, having a rotating impeller O, a separating box P on the side thereof connected to the mixer by a passage R, and by a flexible hose or pipe S at the bottom. In carrying out a test the mixing vessel N contains the circuit water, and eucalyptus oil or other frothing agent is then added in measured quantities, along with acid or other desired reagents. The impeller O is then rotated at about 1,700 revolutions per minute, and a charge of about 500 grammes of ore is fed in. Sufficient solution is added to fill the separating box P to the level of its discharge lip. The agitated pulp is forced through the passage R into the separating box P, and the "float" or "froth" rising to the surface floats off, or is skimmed off over the lip. The pulp is then continuously circulated by being drawn from the bottom of the box P by the pipe S back into the mixer S by the action of the impeller O. A small trickle of water is added to the vessel N to maintain an overflow of floating concentrates. Steam is applied for purpose of heating by introducing a small steam jet into N.

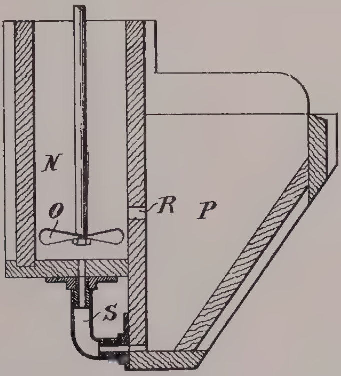


FIG. Z.

FURTHER TESTS ON OTHER PROCESSES.

The processes are so intimately related that it is difficult to give tests serving clearly to differentiate them. Laboratory tests to determine whether any result will be produced can be easily tried without any special apparatus.

TEST FOR POTTER PROCESS.

Take a 200 c.c. beaker and place therein 100 cc. of 3% H_2SO_4 solution. Place this in a water-bath, and raise the temperature to as near boiling point as possible. Stir gently into the solution 30 grammes of ore crushed to 50-mesh. The froth composed of sulphides and CO_2 gas should form at once on the surface of the liquid if the ore is adapted to the process. If the ore contains no calcite or other carbonates, there will probably be no result. In the latter case, of course, a result can be secured by adding to the ore 3% of ground calcite before stirring it into the solution. The concentrate can be removed with a spoon.

The test-tube experiments that formed the basis of the Goyder & Laughton invention are interesting and instructive. Goyder observed that "when heating some Broken Hill sulphides* in a test-tube filled with dilute sulphuric acid, the bubbles, with their sulphide load, travelled to the surface, broke, and then fell back again. By inclining the tube as in 2, Fig. 21, the sulphides rose and travelled up the smooth side of the tube until they met the surface, when, as before, the granule of sulphide fell off, but this time it fell vertically until it met the side of the tube, down which it glided. The inference was that if there was a pocket in the under-side of the sloping test-tube the sulphides should gather in the pocket." A special test-tube like 3, Fig. 21, is easily made, and a number of interesting experiments can be conducted by trials of different ores at varying temperatures and with varying strengths of acid.

TEST FOR DELPRAT PROCESS.

The procedure in this case is identical with that above outlined for the Potter process, except that the solution is made from acid salt-cake. This obviously is only different from th preceding test in that, besides sulphuric acid, there is present in solution a portion of sodium sulphate. Most of the acid sodium sulphate on the market is made by mixing strong sulphuric acid and sodium sulphate in the proportion of about 7 of acid to 3 of sulphate.

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*'Australian Mining and Metallurgy,' Donald Clark, p. 397.

If there is no carbonate present in the ore, add calcite, as with the Potter process.

TEST FOR DE BAVAY PROCESS.

This process depends on the formation of a film of sulphides on the surface of water to effect a separation. Take 100 cc. of water, containing about 0.1% H_2SO_4; add to this 30 gms. of sulphide ore crushed to 50-mesh; add a few drops of petrol, and stir with glass rod for half-minute. Empty pulp on a vanning plaque, and gently rock the plaque so that the liquid alternately covers and uncovers the ore. As these little waves cover and uncover the ore the sulphides are picked up, and float upon the surface. With patience a clean tailing can be produced.

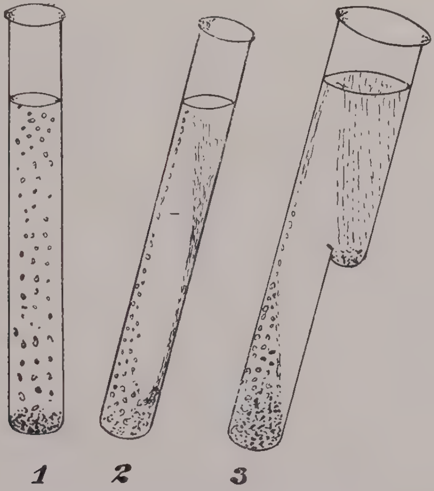

FIG. 21.—Tube for Potter-Delprat Tests.

TEST FOR MACQUISTEN PROCESS.

Take 30 grammes of sulphide ore on a vanning plaque. Add 100 cc. water and a few drops of sulphuric acid. Subject the ore to the same manipulation as in the case of the De Bavay and a similar result will be produced, but much less float material will be secured. No amount of patience will serve, however, to produce a clean tailing. This test serves merely to show the principle on which this particular process works.

TEST FOR ELMORE PROCESS.

What is known as the old Elmore process may be tried in a glass jar of about 1,000 cc. capacity. What is known as a Mason fruit-jar with a screw-top is the best apparatus for this trial. Place in the jar 300 cc. water, 100 gm. sulphide ore, and stir slightly to make a uniform pulp; add 0·5 cc. strong sulphuric acid and 200 cc. thick oil, such as the thick tarry residue of petroleum or a cylinder-oil. Screw on the top of the jar and turn it end-for-end about 20 times, and set aside to settle for a few minutes. The contents of the jar will settle into layers; at the bottom a layer of sand mixed with some sulphides; next above will be a layer of muddy water, and above that again will be a layer of oil containing most of the sulphides (the amount depending on the success of the manœuvre) and some gangue. The oil layer may be removed by adding more water carefully beneath the oil through a tube, and after the oil and sulphides have been removed, the sulphides can be separated from the oil by heat and gentle stirring, when the sulphides will settle to the bottom.

The new vacuum process is more difficult to test in a small way so as to produce a satisfactory result. Probably the best method is as follows: Take a large-mouthed 300 cc. bottle, and fit a stopper with a tube to be attached to a laboratory suction-pump. Put into the bottle 30 gm. sulphide ore, 100 gm. water, one-fifth cc. Texas or California fuel-oil, and one-fifth cc. H_2SO_4. Stir with a glass rod until a uniform pulp is produced, but do not beat any air into the pulp. Place the stopper in the bottle and attach to the suction-pump. Start the pump, and gently shake the bottle to keep the ore stirred a little. As the vacuum is produced the sulphides should begin to rise to the surface and form a layer of froth.

MECHANICAL AGITATION.

A simple laboratory experiment will give a clear idea of the efficiency of this method of providing gas bubbles for the purpose of flotation. Take in one hand a test-tube half full of distilled or ordinary water. In the other hand take a test-tube of distilled or ordinary water, to which has been added the smallest possible drop of any one of the following substances: Oleic acid, kerosene, amyl alcohol, any of the essential oils, camphor, or alcohol. Taking one of the above test-tubes in each hand, shake them violently at the same time and to the same extent. The water in the test-tube that had the drop of foreign substance added to it will, upon ceasing the agitation, be white with occluded air-bubbles of small size; and, depending on the substance used, these bubbles and the milky appearance will last for some time. The water in the other test-tube will, however, show no such appearance; the water is as clear and unclouded in appearance as before shaking. An interesting series of tests can be made in this way, in which the time factor for complete clearing away of the milkiness can be observed. This series of tests will show that those substances which produce the best and the most persistent milkiness are in many instances the best materials to use in flotation processes.

DELETERIOUS SUBSTANCES.

There are some remarkable exceptions to this rule, however, and some of the worst substances that can adventitiously be introduced into flotation-concentration work, as it is understood at present, are excellent producers of air-occlusion.

A beneficial study can be made of substances deleterious to mineral-froth formation. Having performed an experiment as above described to the point of having secured a froth of, say, one inch in depth, one cubic centimetre of a solution of saponin, of a strength of one of saponin to one million of water, is added, and then the agitation is started. It will be observed that the froth will have completely disappeared, and cannot again be reproduced. Probably one pound of saponin introduced into the operations of the largest oil-and-gas flotation plant in the world would completely suspend all useful results for a week, unless all traces of the saponin were completely removed by entire rejection of all the water and ore that had become contaminated with saponin, and the plant would probably require a thorough scrubbing with clean water besides. Many other substances have the same effect (though not so pronounced for the small amounts used); among them are glue, starch, flour, tannin, and ox-gall. On one occasion R. Gilman Brown, consulting engineer to a mining company using the Elmore process, described a peculiar aberration of the process. On a certain day the process discontinued working for no apparent reason, and it seemed impossible to ascertain the trouble. No concentrate was produced for several shifts. He investigated to determine whether the water contained anything deleterious, and noted that these erratic results had begun after they had changed from the ordinary brook water, which had become exhausted in the dry season, to water that had been stored in a series of small lakes and ponds in a peaty marsh. He found that there was probably enough tannin or analogous compound in the marsh water to destroy flotation, especially if the water was brown. The water was at once changed, and no further trouble ensued.

PROBLEMS SUGGESTED FOR RESEARCH.

There are a number of problems, some already mentioned, that will repay scientific investigation. A few are here noted :

What is the significance of the hysteresis range in the contact angle between the rising and falling meniscus ?

What is the real function of acid in flotation processes ?

Can a feasible scheme of flotation treatment be devised for carbonate ores ?

Can a non-acid flotation treatment be devised ?

What is the significance of the fact that a too strong acid medium in oil-and-gas flotation methods is fatal to good work ?

Why are some of the substances that produce good air-occlusion bad flotation-concentration reagents ?

Why will air not replace carbonic acid gas in the Potter process, all other conditions being equal ?

What is a froth ?

Would some method of producing coagulation without the aid of acid and oil enable one to introduce directly the gas-film adhesion-factor, and so secure flotation without oil or acid ?

CHAPTER VI.

THE POTTER–DELPRAT PROCESS.

The inventions which form the basis of this method were the work principally of two men working entirely independently—Charles V. Potter and Guillaume D. Delprat. It is another in a long line of instances where two minds arrived simultaneously at practically the same scientific point. The ideas are so similar that litigation soon developed; but, unlike many engaged in the development and application of metallurgical patents, these people soon wisely compromised. Potter had priority of patent date, and the slight differences between their processes, it must be admitted, would put a judge in a quandary. The basis of compromise was that Delprat was free to use the process in Australia, while the Potter Sulphide Company acquired all the patents and the right to license the use of the process. The amount asked for royalty in the past was 2s. 6d. per ton of concentrate, which amounts to about one shilling per ton of ore of the Broken Hill type.

After what has been said of the general theory of flotation processes, it is not necessary to give *in extenso* the whole of the principles set forth in Chapter IV. The Potter-Delprat is one of the processes making use of surface tension phenomena. The act of flotation is accomplished by virtue of the natural adhesion of carbon-dioxide gas bubbles to particles of sulphide, and the result of the manipulation to which the material is subjected is the formation of a dense froth of bubbles and mineral, which floats at the surface of the apparatus. No substance other than acid is used in the process, as in most of the other processes for the purpose of enhancing the adhesion of gas films, but there may be organic substances in the ore which, upon the addition of acid, yield gummy organic compounds that selectively adhere to the ore. It is difficult to understand the working of this process without some such theory to account for the gummosity of the concentrate. It is worth noting that this process is the only one that secures flotation by the buoyancy of carbon dioxide gas, all the others claiming to use air alone as the active flotation gas. To differen-

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tiate it from the other flotation processes this one may be called an 'acid-flotation process', or more correctly a 'carbon-dioxide gas-flotation process'. The gas is generated in the pulp by the action of hot dilute sulphuric acid, or acid salt-cake, on the carbonates which occur naturally in the gangue.

This process, as in use at the Broken Hill Proprietary mine, treats the tailing from the lead-concentrating mills. The tailing assays roughly 20% zinc, 6% lead, and 6 oz. silver. The gangue is a mixture of quartz, rhodonite, and garnet, with about 3% of calcium and iron carbonates. The last-named are of prime importance in the process. The material to be treated is taken from the dumps and re-crushed to about 40-mesh in grinding-pans. After removal of the water used in crushing, the material is hauled to the treatment plant, where it is delivered into bins (see Fig. 22)*.

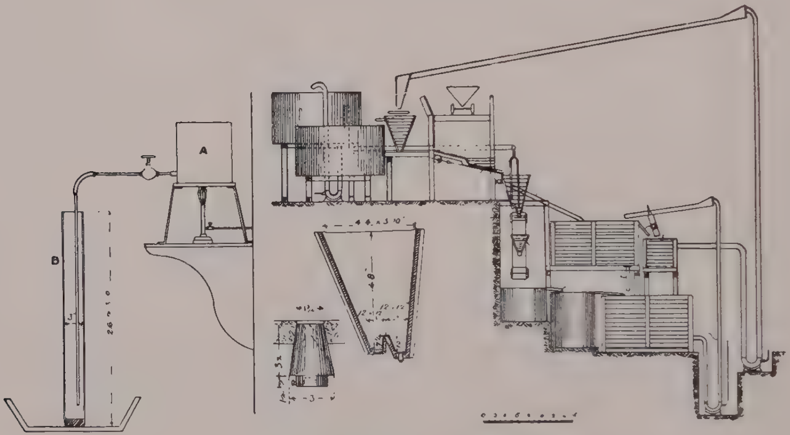

FIG. 22.—Section of Potter-Delprat Plant.

From these bins it is fed automatically into flotation vats, where the separation takes place. These vats are inverted wooden pyramids (see Fig. 23), lined with sheet lead. It will be noticed that these vats have two pockets at the bottom—one with and one without an outlet. Iron pipes introduce the solution into the vat close to the bottom, and so aid in stirring the material. One of these pipes discharges into the blind pocket A, and the other into the pocket with an outlet. The blind pocket collects all heavy stones, bolts, nails, etc., which otherwise would obstruct the outlet. A 2% to 3% solution of sulphuric acid is introduced into the vat at a temperature of 82° C., but as the quantity introduced is more than can run through the bottom outlet, a large quantity passes over the top by an overflow specially arranged for this purpose. The tailing is then fed mechanically from the bin into the vat, above the blind pocket. As the material falls into the pocket it is washed over the partition B, which separates the two pockets, and the gangue passes away through the outlet. On its way down the vat, however, the acid acts on the carbonates contained in the ore, and produces bubbles of carbon dioxide gas. This gas shows a selective action, and adheres to the particles of

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*A paper, read as a presidential address, by G. D. Delprat, before the Australian Institute of Mining Engineers, and published in its 'Proceedings' for Sept., 1906.

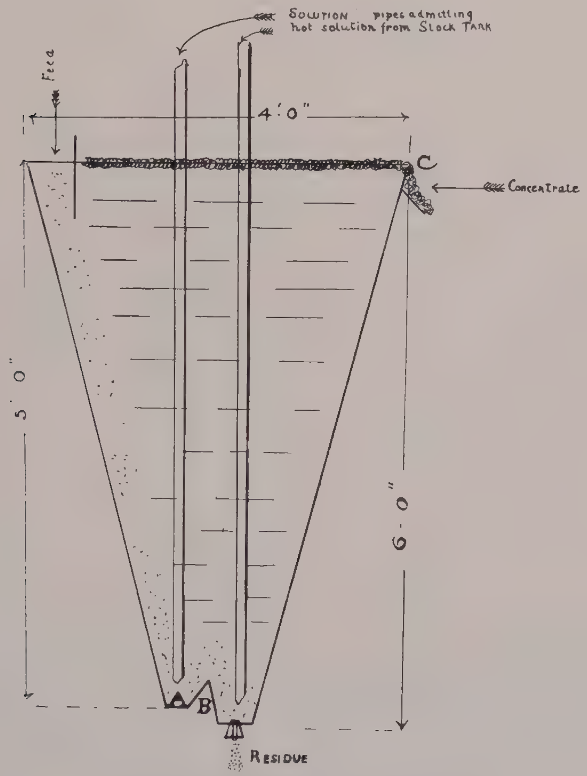

FIG. 23.—Potter-Delprat Frothing Box.

blende and galena, but not to the particles of gangue. The adhering bubbles cause the particles of blende and galena to float; they come to the surface in the form of a dense froth, and are washed away by the current over the lip C.

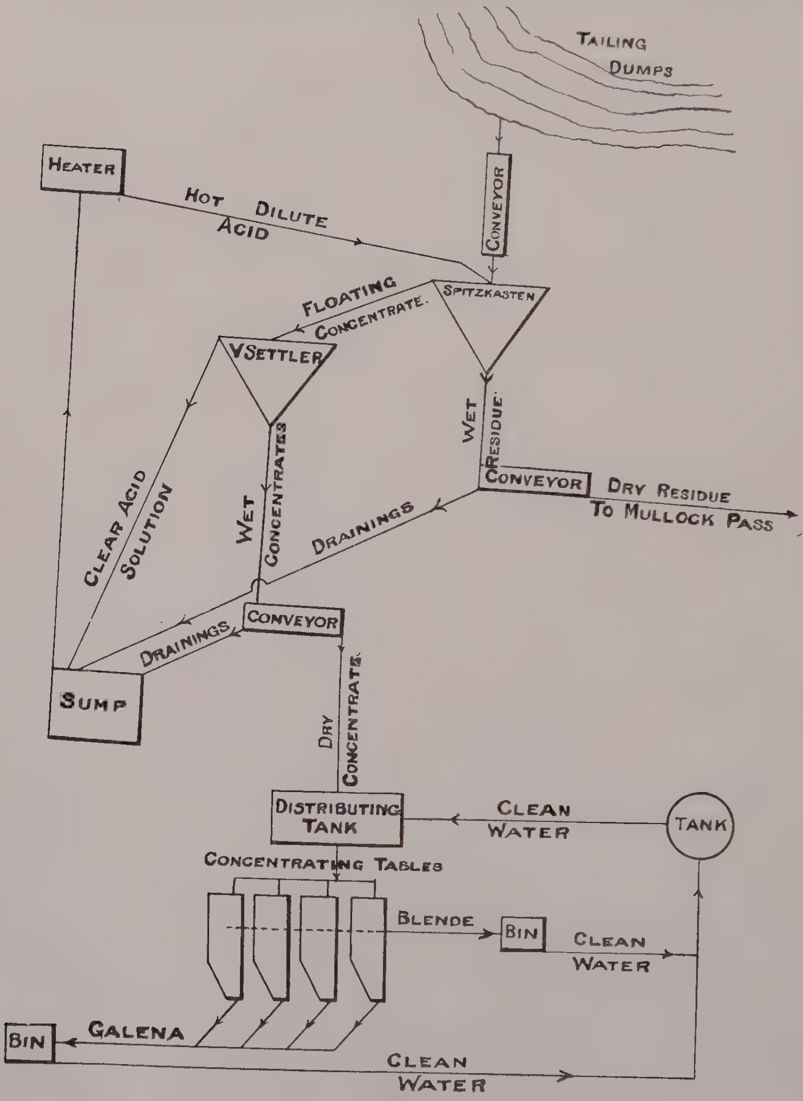

FIG. 24.—Flow-Sheet Potter-Delprat Plant.

The overflows of all the vats pass to one launder, which discharges into a set of wooden tanks, where on cooling the particles of blende and galena lose their bubbles of gas, and fall to the bottom.

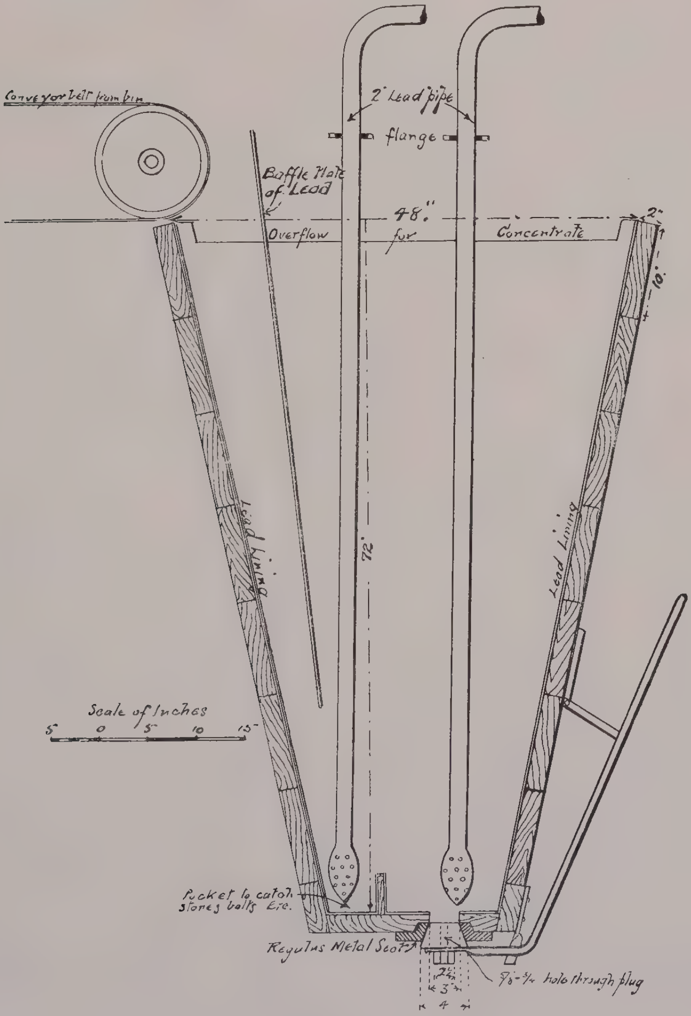

FIG. 25.—Potter-Delprat Frothing Box.

When the tank is full, another tank is filled while the contents of the first is being drained, washed with clean water, drained again, and finally loaded into railway trucks. A flow-sheet for the process with the re-treatment of the concentrate is shown in Fig. 24.

It is found that each flotation vat can treat from 10 to 12 tons of material per hour, but three vats are generally used for this amount. The speed depends greatly on the fineness of the material. About 200 tons of concentrate is the daily product of three units, but as much as 300 tons per 24 hours has been produced by each flotation vat. Another form of vat for the same process is shown in Fig. 25.

The bottom outflow from the vats carries all the gangue with it. The solution and gangue together fall on a 3-ft. india-rubber travelling belt, with side rollers to make it into a trough. The belt runs uphill, by which means the solution is separated from the tailing and run into a sump, while the solids settle on the belt. On the arrival of the tailing at the end pulley of the belt it is sufficiently dry to be used as filling for the underground workings of the mine.

The temperature most suitable is 80° C. ; in order to reach this, superheated steam at 260° C. is introduced into the solution vats, which stand on a high enough level to command the whole plant. Air-lifts are used to return the spent solution from the drained tailing and concentrate to the solution vat. One treatment only is given to the material in this process, and in this regard the process has an advantage over several of the others which require repeated treatments to secure commercial recoveries.

As there are no moving parts in the plant, except the mechanical feeders and travelling belt, the cost of repairs is small. Two engines of 10 h.p. each supply all the power required, except that required for the air jets.

It was found in the experiments conducted by the Zinc Corporation that the addition of some substance that would produce a coagulated appearance to the pulp was of material benefit. Among other substances tried was resin, but the best substances for the purpose of producing this effect are oils. This brings us back to the question of the enhancement of the inherent quality of the sulphide particles to adhere to gas films by coating the sulphide particles with films of oil, and shows the near relationship of all the flotation processes. Recent Potter patents have sought to cover this idea. It has been said that the present users of this process do not use any oil in their operations, and when I visited the plant on the Proprietary mine none was being used. At first glance it would appear that the concentrate from this process would be readily amenable to re-treatment by concentrating tables; but the Zinc Corporation found that the concentrate had a 'gummy' or 'sticky' quality, which rendered such an operation extremely difficult. This is surprising, as the sulphuric acid or any of the salts derived from its use are apparently sufficiently soluble in the table water to render the sulphides loose and sandy. The explanation may be that the hot sulphuric acid forms with the organic matter, which is always present in tailing heaps, insoluble 'gummy' or 'sticky' compounds which exercise a preferential adhesion to the sulphides.

The apparatus and equipment of this method has arrived at a state of finality that some of the others have not reached, the reason being the great simplicity of the idea involved. The cost of the plant is obviously low. The equipment is such that it can be built on the spot from easily procured materials. Ordinary timber, with sheet lead for a lining of the flotation-boxes, is all that is needed. The cost per unit of the Potter-Delprat plant should not exceed £200, including installation.

In the early development of the process, difficulty was encountered in finding a machine or flotation-box that would save the concentrate, the trouble being that the bubbles would break and drop their load. This was overcome by Goyder & Laughton in a machine having a series of traps. Later, when it was discovered that a froth prevented the bubbles breaking, it was an easy step to see that if the flotation-boxes were crowded to a high capacity the froth itself, if produced in sufficient quantity, would act as a blanket, and so prevent the troublesome breaking of the bubbles.

APPLICATION.

Block 14.—The first plant was erected at Broken Hill, on the Broken Hill Proprietary Block 14 company's mine, in 1903, to treat middling from the lead-concentrator. Aside from the small amount of zinc concentrate produced by the Sulphide Corporation by magnetic concentration, this marks the beginning of the Broken Hill zinc industry. The first machines installed were of the Goyder & Laughton type, which were of complicated design and low capacity. In 1904 the Delprat pan (Figs. 23 and 25) was introduced instead. After 1905 this plant was shut down owing to lack of material for treatment. Fig. 25A is a flow-sheet of this plant.

PROPRIETARY.—Concurrently with the above plant, in 1903, the Broken Hill Proprietary installed the Delprat process, the inventor—G. D. Delprat—being the general manager of the mine. This plant in 1904 was treating 3,500 tons per week, which was increased to 5,500 tons in 1905. During 1906 the plant treated 235,000 tons, and a system was installed whereby the material from the dumps was first sent to tables to recover some lead, then deslimed to provide material for sintering, and then re-ground for

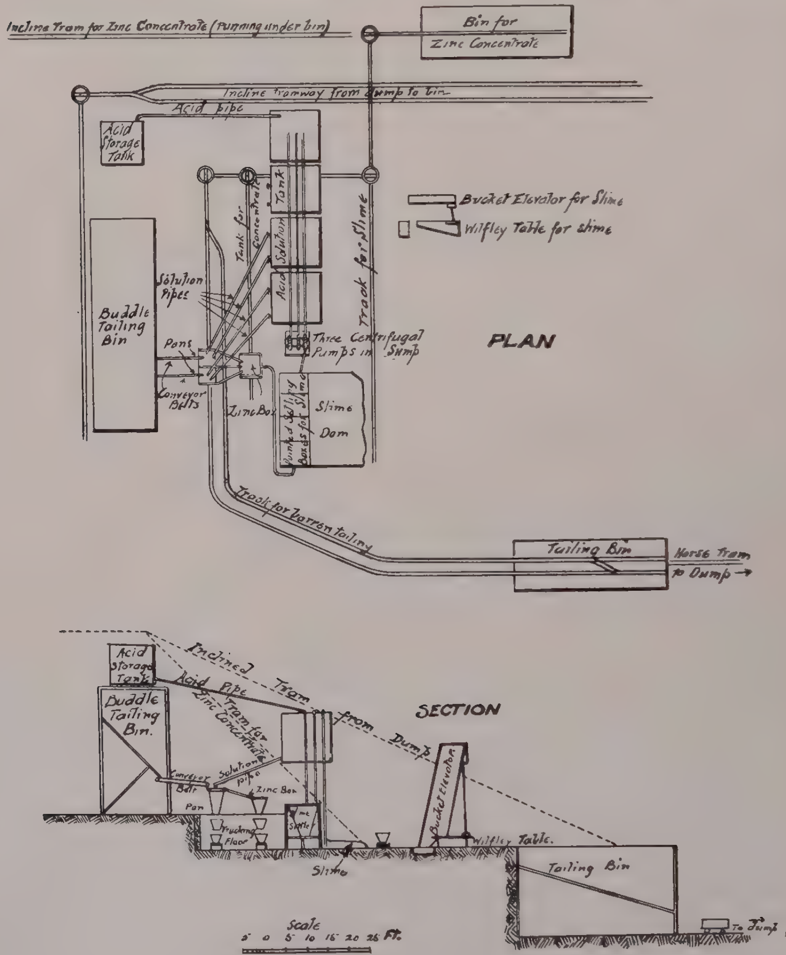

FIG. 25A.—Flow-Sheets, Block 14, Potter Plant.

the flotation process. Litigation had begun between Potter and Delprat, but was settled in 1907. By the end of 1907 this plant had produced 180,000 tons of zinc concentrate. The plant worked steadily during 1908, and produced 65,000 tons of concentrate. For five months of 1909 it was idle because of the strike, but in the remaining time produced 52,000 tons of concentrate. In 1910 the production was 70,000 tons, and in 1911 92,000 tons. The total production has been 459,000 tons of concentrate from over 2,000,000 tons of tailing treated.

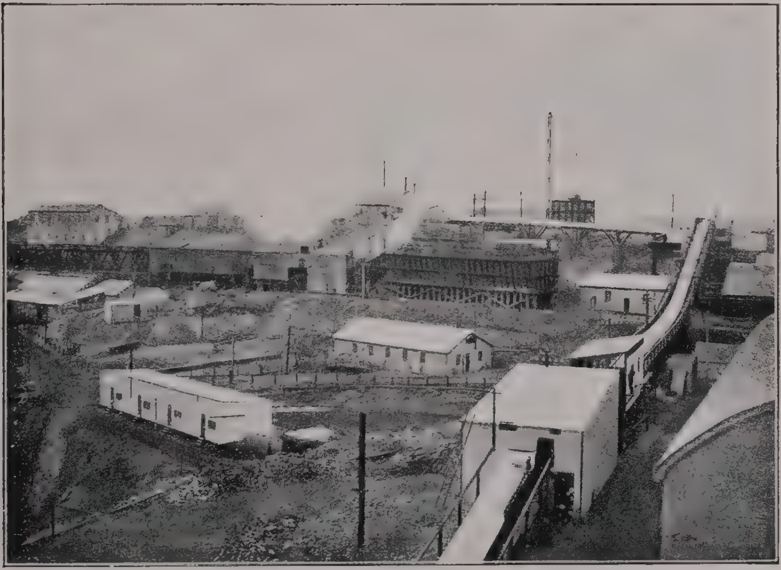

FIG. 26.—Proprietary Flotation Plant.

Figs. 26 and 27 are photographs which give some idea of the magnitude of the operations. The concentrate assayed nearly 46% zinc, 8% lead, and 13oz. silver per long ton. During the first half of 1910 the plant was re-modelled at a cost of £8,000 by the introduction of cast-iron flotation-boxes, presumably of the same design and principle as those shown in Figs. 23 and 25, and by the introduction of conveyors from the heaps and steam-shovel excavators.

For several years it was not possible to treat slime by this method, but an ingenious idea of E. J. Horwood has solved the difficulty. He found that as the slime contained a large amount of finely ground calcite, the carbon dioxide gas was generated too rapidly, and the bubbles grew too fast to attach themselves effectively to the sulphides. He therefore introduced a centrifugal pump between each two of a series of separating boxes for the purpose of mechanically breaking the bubbles to small size. This violent agitation also, no doubt, assisted in coagulating the slimed sulphides; this, together with the breaking up of the bubbles, enabled the frothing to proceed on this material as easily and perfectly as upon any other class. A plant is now in operation which produces about 1,000 tons per month of concentrate from material 90% of which will pass a 200-mesh screen.

FIG. 27.—Zinc-Tailing Heaps.

ZINC CORPORATION.—In 1905 this company began its operations by an installation of the Potter process on the British mine, where they had purchased a large dump of tailing and middling. This plant was intended to treat 2,000 tons per week. The plant ran intermittently through 1906, with many alterations, and finally the process was abandoned.

GILLIES.—The Gillies company purchased a large dump on the Block 10 mine, and erected a plant in 1906 with an estimated capacity of 2,000 tons per week. In 1907 this plant produced 7,700 tons of concentrate during the periods when it was being altered, but finally the Potter process was abandoned, and after a short trial of the Minerals Separation process the plant was dismantled and the tailing sold.

WORKING COST.

The working cost is difficult to calculate. In the Broken Hill Proprietary Co.'s half-yearly report for the period ended December 31, 1910, the tonnage is given as 179,713, and in the working account £45,213 18s. 1d., or 5s. 0¾d. per ton, is charged to the zinc plant for 'wages, salaries, and expenses'. There are, however, items of electric light, machine shop, assaying, electric power, experimental account, fire account, fuel and fluxes, water, locomotive traction, and horses and drays, a portion of which should be charged to the zinc treatment. The previous half-yearly report gave 103,792 tons treated at a cost for 'wages, salaries, and expenses' of £44,999 19s. 4d., or 8s. 11d. per ton treated. The same list of other items was also given. It is a hopeless task to obtain the actual working cost of the process from these reports. We can, however, arrive at one useful deduction, namely, that 30lb. of acid was used per ton treated. The average market price of acid in Broken Hill is about one halfpenny per pound, so that the cost of acid was 1s. 3d. per ton of material treated. The sum of £4,846 was spent for water during this period. As water costs 5s per 1,000 gallons at Broken Hill, this means that 19,384,000 gallons of water were used in the operations. About 100 gallons of water per ton is the loss at Broken Hill, and these figures fit sufficiently well to justify the inclusion of 6d. for water. The heating of the pulp to 82° C. is also a charge which can be accurately deduced from a knowledge of local conditions, and amounts to nearly 6d. per ton. The power charge is practically confined to the items of pumping solutions and elevation of pulp. This charge cannot be ascertained from the published reports; an estimate would be 3d. per ton. Tabulating these and other items, the following table gives the items which concern the actual process itself, excluding all the expense of tramming, de-sliming, and grinding:

	s.	*d.*
Power		3
Acid	1	3
Supplies		2
Labour		4
Fuel		6
Assays		1
Water		6
Superintendence		1
General		3
	3	5

The acid would actually cost the company less, but is charged at ½d. per lb. for the purpose of comparison.

RECOVERY.

In the report for the last half of 1910 figures are given from which a fair idea of the recovery can be obtained. To do this it will be necessary to assume the metal content of the material treated. There are no authoritative figures relating to this, except in the Annual Report of the Department of Mines of New South Wales for 1904, where the Proprietary company is said to have 2,500,000 tons of tailing assaying 17% zinc, 4% lead, and 6oz silver per long ton. This, it is believed, is too low. Using these figures, the recovery and products are as follow :

		Assay			Content		
	Tons	Zinc	Lead	Silver	Zinc Tons	Lead Tons	Silver Oz
Feed	179,713	17.00	4.0	6.00	30,551	7,189	1,078,278
Concentrate	43,907	46.06	6.3	12.49	20,224	2,766	548,398
Tailing	135,806	7.70	3.3	3.90	10,327	4,423	529,880
Recovery %		66.2	38.5	50.9			

Ratio of concentration 4.1 to 1

For the six months ended November 29th, 1911, 137,249 tons were treated, yielding 3,136 tons of lead concentrate assaying 54% lead and 28 oz. silver, and 48,192 tons of zinc concentrate assaying 45% zinc, 7% lead and 13 oz. silver. The concentrate being produced now assays 47% zinc. Production since then has been as follows :

BROKEN HILL PROPRIETARY CO., LTD.

TAILINGS PLANT.

Half Year to	Treated Tons	Zn. %	Pb. %	Ag. oz.	Produced Concentrates Tons	Zn. %	Pb. %	Ag. oz.
May 31, '12 ..	168,309	16.5	3.5	6	46,005	46.8	6.9	12.8
Nov. 30, '12..	148,132				42,003	46.2	7.2	13
May 31, '13 ..	167,827				41,771	46.1	7.3	12.9

SLIMES PLANT.

Half Year to	Treated Tons	Zn. %	Pb. %	Ag. oz.	Produced Concentrates Tons	Zn. %	Pb. %	Ag. oz.
May 31, '12 ..	9,455	19	13.6	17	3,209	36.6	20	29
Nov. 30, '12..	17,414				5,472	35.5	16.5	33

This latter slimes plant was erected to put into use a new idea in regard to slimes. When treating slimes by the ordinary Potter-Delprat process the bubbles of CO_2 gas form too rapidly, and become so large that they are not an effective froth formation agent. This difficulty is remedied by carrying on the process in an apparatus which gives the mass thorough agitation, so that the bubbles were broken up or emulsified. The froth formed by this means is the same in appearance as the other frothing processes.

CHAPTER VII.

THE DE BAVAY PROCESS.*

This process is the result of the researches of A. J. De Bavay. The patents are owned by the De Bavay Sulphide Process Company, which lets the use of the process on a royalty. By a recent combination with the Minerals Separation, Ltd., these patents have been merged with those of the latter company.

De Bavay, as reflected in his early patents, was developing a process in which the surface tension of the liquid, without the extraneous aids of oil and acid, was the idea involved. The process works on the principle of the 'greased needle', and there is none of the frothing which characterizes the Potter-Delprat, Minerals Separation, and Elmore processes. During the operation of the process there is simply a film of sulphides floating just as indicated in Fig. 6, Chapter IV. De Bavay, in the course of the development of his process, recognized the value of oil and acid as accelerating factors in surface tension processes, and now uses oil for the same purpose as the others. The similarity in many ways of the early De Bavay patents to that of Bradford is apparent.

The first plant was erected on the mine of the North Broken Hill Mining company. This plant was altered and re-modelled many times while the process was being developed, and no complete story of these changes and experiments will probably ever be written, nor is it necessary. The plant did much good work all through the period of development from 1905 to 1908, when a measure of finality was reached in the methods. The process, as worked here in the later stages, is as follows: The tailing from the lead mill is first de-slimed, leaving practically a clean sandy product. The slime is discarded. The clean sand, crushed to about 40-mesh, is then fed into a mixing device, known locally as the A.Z. agitator, and mixed with cold acid solution of 0.19 strength. A photograph of the machine is shown in Fig. 28. This agitator is provided with a central tube worked with a rack and pinion for raising and lowering the upper end of the tube. The proportion of acid solution added is four or five of solution to one of material. Thorough agitation is imparted to the mixture for a considerable time. The agitator is run at high speed for the purpose, as explained by the millman, of cleaning the surfaces of the mineral particles. This operation being completed, the speed of the agitator is reduced and the centre tube lowered so as to draw off the bulk of the solution, upon which is floating some metallic scum. When the excess of the solution has been removed, the centre tube is raised, clean wash-water added, and agitation renewed at high speed. After thorough washing, the speed of the agitator is again reduced, the excess of liquor removed as before, and a second washing effected to free the tailing of any acidity remaining. The scum of metallic particles drawn off is treated on vanners for the recovery of lead concentrate. The cleaned tailing is next conveyed to the 'oiling' vat. In this vat, which is provided with an agitator, the material is mixed with water, to which a definite proportion of oil has been added, and the whole mass thoroughly agitated to bring the metallic particles into contact with the oil. The oil is composed of one part of castor oil and four parts of low-grade kerosene; two to three pounds of oil to one ton of ore is used, and also some chlorine gas. From this oil-mixer the oiled pulp is elevated by means of a montejus and compressed air to the first tier of eighty-eight flotation cones,

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* Since the publication of the first edition there has been some criticism of the author's statements in regard to this and other processes. Before preparing the copy for the second edition all the owners of processes were given an opportunity to correct the statements, and they have nearly all refused to do so. Therefore the author adheres to all the statements as they stand.

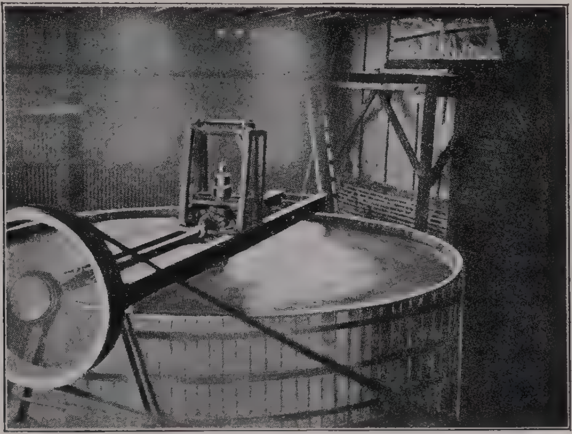
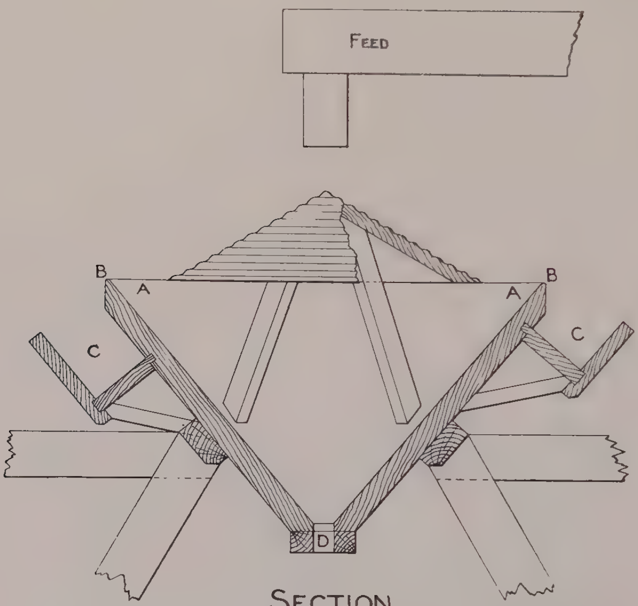
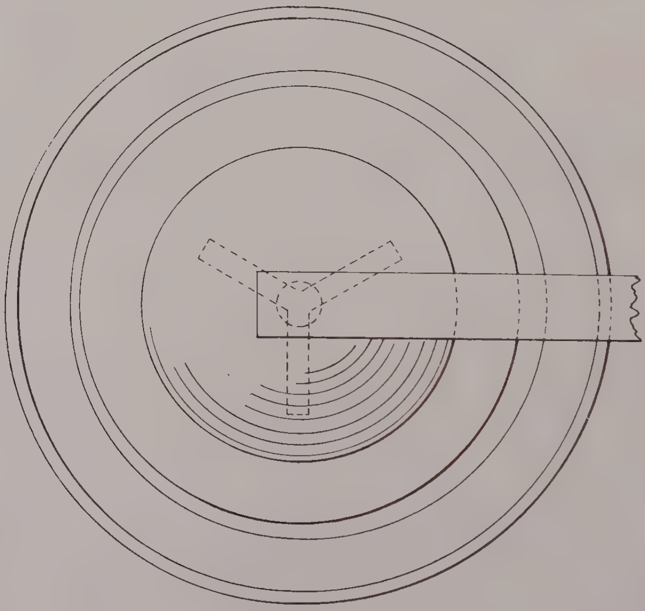


FIG. 28.—A.Z. Agitator.



SECTION



PLAN

SCALE OF FEET

FIGS. 29 & 30.—Sketch of De Bavay Flotation Cone

one of which is shown in section in Fig. 29, and in plan in Fig. 30. The material is fed to the cone at the top, and runs down over a series of corrugations to the water level A, where the sulphides float at the surface of the water (Fig. 30), and pass over the lip B into the launder C. The tailing, on the other hand, sinks through the surface of the water at B, and passes down the box and out at D. It is then fed to another similar cone and box with some further recovery of sulphides, and so on to a third and fourth cone and box. Throughout this manipulation, including the acid washing, the oiling, the raising with compressed air, and the flowing over the corrugated cone, the sulphide particles are repeatedly aerated, and as a result, especially after the oiling, take up their adhesive air films and float at B in exactly the manner shown in Fig. 6, Chapter IV. The function of the chlorine may be that of gasification of the sulphide particles, or, through the formation of hydrochloric acid, it might indirectly assist by acidulating the solution; or it may have some other obscure and secondary uses. The subjecting of the oiled pulp to compressed air may be an essential part of the operation. If so, the analogy to other oil-and-gas processes is close.

North Mine Plant.—The De Bavay plant on this mine was erected in 1905, and began operation in 1906. The first unit was estimated to treat 10 tons per day, and this was increased during the latter year until the plant was treating 300 tons per week. During 1907 more or less experimental work was done, and by the close of the year £65,000 had been expended on the plant. It was then considered capable of treating 1,700 tons per week, and during the year 17,000 tons of tailing were treated. In 1908 the capacity of the plant was further augmented, and a total of 74,200 tons was treated during the year. The 22,590 tons of concentrate produced this year averaged 47.5% zinc, 7% lead, and 6oz. silver per ton. This was the best concentrate produced by any flotation process at Broken Hill, and in this regard the De Bavay process continues to hold the lead. This factor is due to the careful de-sliming of the material before treatment. In 1909, 30,000 tons of concentrate was produced, assaying 48.5% zinc, 6.4% lead, and 5.9oz. silver. This high-grade concentrate was a noteworthy product. During the first half of 1910 the plant continued operations, but in August of that year it was closed because of the new phase of operations under the ownership of the Amalgamated Zinc, Ltd.

AMALGAMATED ZINC. — This company took over the Australian rights to the De Bavay process, the mill on the North mine, and all the tailing contracts of the De Bavay Treatment Company. It purchased tailing dumps, and in 1909 began the construction of a large new mill at the extreme north end of the Broken Hill district. The first section of the new mill was started in March, 1910; the second section in August, and the third in October. The capacity of the whole plant is 2,800 tons per day. A re-treatment plant, consisting of tables, was installed, and the whole or a part of the flotation concentrate is treated thereby for the recovery of lead concentrate.

The tailings which are available for treatment by this plant are as follows: From the South mine 650,000 tons from the dump, and the current production of the lead-concentrating mill for ten years, a total of 2,750,000 tons, assaying 19% zinc, 5.5% lead, and 5 oz. silver. This material contains 5% to 7% of manganese, and gave great trouble to the other processes which tried to treat it. From the North mine 200,000 tons of dump tailings, and the current production for ten years, a total of 1,500,000 tons, assaying 18.5% zinc, 4% lead and 8 oz. silver. From the Block 10 mine 300,000 tons of dump tailings assaying 16.5% zinc, 4.5% lead, and 8 oz. silver. In comparing this plant and process with others it should be kept in mind that this material is the cream of the district. It is of high grade, and has been sized, and for this reason is the most easily treated of any zinciferous material now being used.

Owing to the small capacity of each of the three units, this plant covers a large area. The cost of the plant exceeds, per unit of tonnage, that of any of the other flotation plants, being £250,000, or £90 per ton daily capacity. Some auxiliary works were included in these figures, such as sulphuric acid plant, but it is certain that the De Bavay plant proper cost in excess of £70 per ton daily capacity for a plant of 2,800 tons per day.

RECOVERY.

If one of the best month's operations is taken and the amount of the material treated is calculated from the figures given in the prospectuses and Government reports and from what is known otherwise of the district, the recovery by the De Bavay process works out as given in the following tables. We are, however, in

CHAPTER VIII.

THE ELMORE VACUUM FLOTATION PROCESS.

If water taken from an open vessel where it has been exposed to the air at ordinary temperature and pressure be confined in a glass vessel and subjected to a nearly complete vacuum, it will at once be evident that the water contained a gas in solution; because, as the vacuum increases, the gas—which in this case is air—will be seen forming in minute bubbles on the walls of the vessel, or at any other available points. At sea level and at ordinary temperature the quantity of air which open water holds in solution amounts to about 2.2% of its volume. This solution of air is explained by the law of Henry and Dalton, viz: the amount of a gas which will go into solution in a liquid varies in general directly as the pressure and inversely as the temperature.

If we subject a pulp of acidified water and crushed ore to an operation whereby a small amount of oil has been applied to the sulphide particles in a suitable mixing vessel, and then subject this oiled, acidified pulp to a vacuum, the air in solution in the water is at once released, and attaches itself to the convenient points and angles of the oiled sulphide particles in the form of small bubbles, which gradually increase in size until they are sufficiently large to overcome by their buoyancy the force of gravity acting on the sulphide particles. When of sufficient size for this purpose, the bubbles rise to the surface of the pulp, carrying along with them the sulphide particles; at the surface a froth, composed of air bubbles and mineral, forms, and is removed over a lip.

Francis E. Elmore invented an apparatus in which this operation is performed. This apparatus is unique in its features, and it is allowable to marvel at the ingenuity displayed in its invention.

The apparatus is shown in the accompanying sketch, Fig. 31. The pulp from the crushing mill flows continuously into the mixer A, into which also are introduced small quantities of oil, and, if required, of acid also, at the point B. The agitation is done by the rotation of the beaters C. The agitated pulp flows continuously from the mixer into the funnel D. The concentrate discharge-pipe E and the tailing discharge-pipe F are both sealed with water in the tanks G and H respectively. The upper end of the feed-pipe D enters the centre of the conical separating vessel I. Upon the application of a vacuum through pipe J, the pulp from the mixer is caused to ascend the feed-pipe and fill the conical chamber I. The rate of flow of the pulp down the pipe F being slightly less than that up the feed-pipe D, a small amount of the liquid overflows the lip of the annular space K, this quantity of

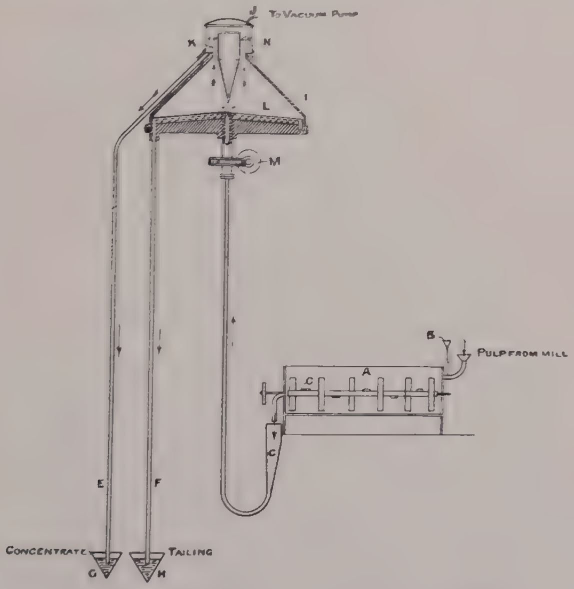


FIG. 31.—Diagram of Elmore Vacuum Machine.

liquid being sufficient to carry floating sulphides down the pipe E into the tank G. The rakes L are caused to rotate slowly by means of the worm and wheel M, the angle of the rake-blades being such as to cause the water-wetted gangue in the pulp to travel from the centre to the periphery of the conical chamber, whence the gangue continuously discharges down the pipe F. The feed-pipe D is usually about 25 to 30 ft. long, the tailing and the concentrate pipes E and F being a few feet longer, so that in effect the feed-pipe and tailing-pipe form the long and the short leg of a syphon; thus the power is supplied by the falling column of pulp in the tailing-pipe. So long as a continuous flow of pulp is supplied to the mixer, a continuous and entirely automatic discharge of tailing and concentrate is secured. The annular space K is surrounded by a thick glass cylinder, or by a metal cylinder with one or more thick glass windows, through which the discharge of the sulphides over the lip of the annular ring may be observed.

Fig. 32 is a photograph of the separating vessel I. The capacity of each unit is from 30 to 50 tons per day, depending on the nature of the ore. The apparatus is constructed of metal, with the exception of the glass windows, and the mixer is a simple wooden trough with wooden beaters. The power required for a 5-ft. unit is said to be 2 to 2½ h.p., including that required for driving the vacuum pump, mixer, and separator. The apparatus is usually constructed in standard units, the conical separating chamber of which is 5 ft. diameter. Including the mixer, conical separating chamber,

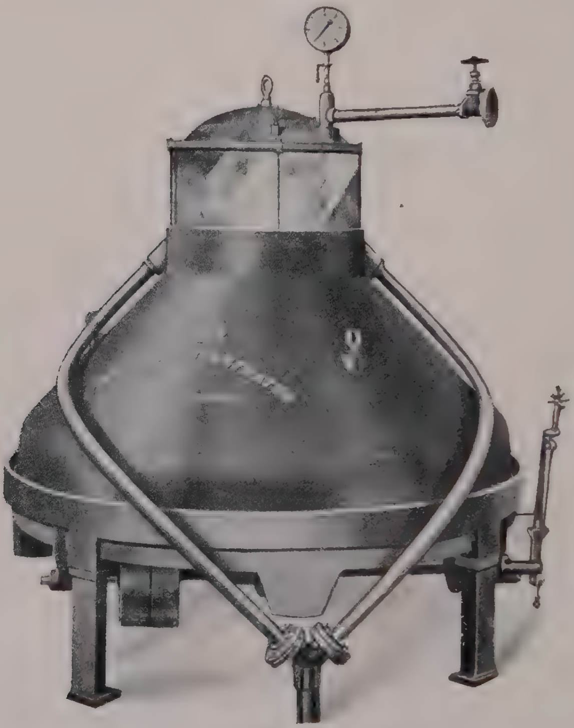


FIG. 32.—Elmore Vacuum Machine.

vacuum pump, all piping, etc., complete, the unit costs, f.o.b. London, approximately £350. The capacity of the apparatus naturally varies with the kind of ore to be treated, the fineness to which the ore has to be ground, and other conditions; but a 5-ft. machine will ordinarily treat from 25 to 45 tons of crude ore per 24 hours.

The cost of the plant is low for so large a capacity. No expensive foundations are required, because the beaters in the mixing cylinder only make 30 to 40 r.p.m., and the rakes in the conical separating chamber only one to two revolutions per minute. Vibration is, therefore, entirely absent. No sizing of the pulp is required, and the operation of the plant is entirely automatic.

The quantity of oil and acid required is not the same for all ores, but usually amounts to not more than a few pounds, say from 3 to 10 lb. per ton of ore treated. A large variety of oils and similar substances have been tried and found suitable: Californian crude oil, Texas crude oil, Texas residuum, fuel oil, Russian crude, Borneo, Sumatra and similar cheap oils, tars, blast-furnace oils, olive-oil residues, oleic acid, kerosene, a variety of light oils, and fish oils.

WORKING COST.

The working cost must vary with the locality and the cost of supplies and labour. For the flotation-concentration at Broken Hill, exclusive of crushing, sizing, and any after-treatment of the concentrate, the working cost has been given as, roughly, 3s. per ton. As these figures were derived from a plant where sulphuric acid was comparatively cheap, it would be safe to take a round figure of four shillings per ton. In detail the figures referred to are as follow:

MEN EMPLOYED FOR SIXTEEN MACHINES.

Vacuum floor	1
Mixer floor	1
Discharging floor	1

Three shifts per 24 hours.

	s.	d.
Cost in grinding section ..	1	3.96
,, flotation section ..	2	4.16
,, drying section	1	3.64
,, re-treatment section ..		7.48
Royalty	1	0
	6	7.06

THE AMOUNT OF AIR.

If the pulp was made up in the ratio of 4 tons of water to 1 ton of ore, and if the ore was of the Broken Hill type, this would be 4 tons of water to about half a ton of sulphides. The water contains 2.2% by volume of air in solution, and it may be assumed that the vacuum releases 2% by volume. Four tons of water is 142 cubic feet; 2% of this is 3 cubic feet of air released for the purpose of floating half a ton of sulphides. Three cubic feet of air loaded with sulphides to an extent just sufficient to remain in suspension would require 3 by 63 lb. of sulphides = 189 lb. of sulphides, or considerably less than half a ton. There is enough air in a pulp of 1 ton of water to 1 ton of ore to lift 60 lb. of concentrate. The following table gives the amounts of air for pulps of different proportions :

Proportion water to ore.	Cubic feet of air available in this water.	Lb. of sulphide this will float.	Percentage of mineral in ore.
1 to 1	.75	60	2.7
2 ,, 1	1.50	120	5.4
3 ,, 1	2.25	180	8.1
4 ,, 1	3.00	240	10.8
5 ,, 1	3.75	300	13.5
6 ,, 1	4.50	360	16.2
7 ,, 1	5.25	420	18.9
8 ,, 1	6.00	480	21.6
9 ,, 1	6.75	540	24.3
10 ,, 1	7.50	600	27.0

As the proportion of water to ore rarely exceeds 6 to 1, and as the ores treated generally yield more than 16% of concentrate, it will be seen that some gas other than that naturally dissolved in the water must be found to effect flotation. This is generally secured by adding limestone to the ore, and then acid at the point where the pulp enters the vacuum chamber. It would be interesting to investigate whether, by limiting the quantity of gas available for froth production, it would be possible to secure differential flotation between lead and zinc sulphides. This machine seems especially adapted to the development of this idea.

APPLICATION OF THE PROCESS.

A large number of trials, both on a small scale and with a full-sized apparatus, have been conducted on a great variety of ores, but it is not claimed that the process and plant are applicable to all ores, although its scope of application is wide.

The process has been applied with success to the concentration of ores which, because of their peculiar characteristics, are quite impossible of concentration by usual methods. For instance, chalcopyrite is readily separated from magnetite and spathic iron gangue; galena and zinc blende from a gangue of barite; and copper sulphides from oxide of tin, leaving the tin in the tailing to be subsequently separated by the usual methods. Zinc, copper. and lead minerals may be separated from garnet and similar heavy gangue; and such minerals as antimony or molybdenum sulphides which, because of their friable nature, suffer prohibitive losses in water concentration, are found amenable to treatment by the Elmore process. Cinnabar and iron pyrite carrying gold are readily concentrated, yielding high-grade products with practically clean tailing. The native metals, gold, silver, and copper, when in a fine state of division, are said to concentrate readily and with very small loss.

Continuous working has shown that the plant is eminently practical; no delicate adjustments are required, wear and tear is to all intents a negligible quantity, and the excellent mechanical design and substantial construction of the apparatus have made breakages almost unknown.

DOLCOATH, CORNWALL.*—In certain parts of this mine the ordinary tin ore of Cornwall is found impregnated with varying proportions of sulphides, principally of copper. This ore is crushed in an Edgar Allen ball-mill, and passed direct to one Elmore vacuum unit. By this operation almost the whole of the sulphides are recovered as a high-grade copper concentrate, which is saleable as such. This concentrate contains a remarkably small proportion of tin, on the average probably not exceeding 2 to 3 lb. of tin per ton of concentrate. Substantially, the whole of the tin oxide is left in the tailing from the vacuum unit. The tailing is subsequently treated by Frue vanners, etc., in the ordinary way for the recovery of the tin oxide. The oil and acid used in no way injuriously affect the subsequent recovery of the tin. This plant was supplied to the Dolcoath company in March, 1907, and yielded highly satisfactory results for some time, giving an

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***Engineering & Mining Journal*, December 14, 1907, by Edward Walker.

extraction of over 90% of the copper contents, but the plant is not now in use.

Ramsley Mine, Devonshire.—Here the ore consists of a mixture of chalcopyrite and bornite with some chalcocite in a slaty micaceous gangue. The average grade of the crude ore is about 2½% copper. It is crushed in stone-breakers, high-speed rolls, and a Huntington mill in the usual way, the pulp being sent direct to one unit of Elmore plant. On the average the concentrate produced assays about 12% copper.

Dolgelly Mine, North Wales.—The ore consists of chalcopyrite with varying proportions of iron pyrite in a schistose gangue. The grade of the ore is usually about 1.2% copper, 0.08oz. gold, and 0.8oz. silver per ton. The ore is crushed by a reciprocating stone-breaker, followed by a 20-head Californian stamp-battery (1,050lb.), through 6-mesh screens. The pulp from the battery is sized on a 16-mesh screen, and the oversize re-crushed in a grinding pan. The pulp is then sent direct to 3 Elmore units, and yields a concentrate of about 12% copper, 0.7oz. gold, and 7oz. silver per ton, the tailing assaying about 0.25% copper, with very small amounts of gold and silver. Prior to the installation of the vacuum plant, much money had been spent at this mine on various forms of water-concentration machines; but, owing to the extreme softness of the copper mineral and the unusually tough character of the rock, the loss of fine material was always prohibitive.

Zinc Corporation.*—The material treated here was a zinc tailing from the lead-concentration plants. The gangue consists largely of quartz, garnet, and rhodonite, being of practically the same specific gravity as the blende with which it is associated; hence no separation by ordinary water-concentration was possible. Much of the tailing on the dump was already fine enough for direct treatment in the Elmore plant; that portion that was too coarse was crushed in 12 grinding pans, sized on improved revolving screens, the oversize being re-crushed in six additional grinding pans. The average assay of the material treated in this plant was about 19% zinc, 5% lead, and 8oz. silver per ton. This yielded a concentrate assaying on the average about 43% zinc, 11% lead, and 17oz. silver per ton. It was found that, if this concentrate was dried and subjected to a sufficiently high tempera-

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**The Mining Journal*, February 20, 1909, by A. Stanley Elmore.

ture to expel the small quantity of oil which it contained, the de-oiled concentrate could then be mixed with water and passed over Wilfley tables, yielding a zinc product assaying 46% zinc, 6.1% lead, and 13oz. silver per ton, and a lead concentrate assaying about 57% lead, 16% zinc, and 37oz. silver per ton. The assay of the final residue depended, to a great extent, upon the more or less oxidized condition of the mineral, much of the material on these dumps having been exposed to atmospheric oxidation for many years; but the following may be taken as fairly representative: Zinc, 5.90%; lead, 2.5%; and silver, 4oz. per ton.

Fig. 33 gives a condensed flow-sheet of the arrangement of this mill, including crushing, sizing, flotation, and re-treatment on Wilfley tables. The plant contained 16 units, and was installed only after exhaustive trials had been conducted with one unit. The mill was in continuous operation for two years, and gave a higher capacity, better grade of concentrate, and greater percentage of extraction than was indicated by the trials with the one-unit plant.

The following table gives the total tonnage treated from the beginning of February, 1908, to the end of July, 1911, inclusive, with the results:

FEED		Tons	714,399
	Assay	Per cent. Zn	19.1
		oz. Ag	7.9
		Per cent. Pb	5.5
FINAL ZINC CONCENTRATE		Tons	241,710
	Assay	Per cent. Zn	46.0
		oz. Ag	13.34
		Per cent. Pb	6.63
FINAL LEAD CONCENTRATE		Tons	20,639
	Assay	Per cent. Zn	15.84
		oz. Ag	36.76
		Per cent. Pb	56.57
ZINC SLIME		Tons	7,977
	Assay	Per cent. Zn	38.85
		oz. Ag	21.11
		Per cent. Pb	13.55
RESIDUE		Tons	452,050
	Assay	Per cent. Zn	4.88
		oz. Ag	3.67
		Per cent. Pb	2.59

PERCENTAGE DISTRIBUTION.

FEED	Per cent.		100
FINAL ZINC CONCENTRATE	Per cent.	Weight	33.8
	,,	Zn	81.4
	,,	Ag	57.1
	,,	Pb	40.6
FINAL LEAD CONCENTRATE	Per cent.	Weight	2.9
	,,	Zn	2.4
	,,	Ag	13.4
	,,	Pb	29.6
TOTAL CONCENTRATE	Per cent.	Weight	36.7
	,,	Zn	83.8
	,,	Ag	70.5
	,,	Pb	70.2
RESIDUE	Per cent.	Weight	63.3
	,,	Zn	16.2
	,,	Ag	29.5
	,,	Pb	29.8

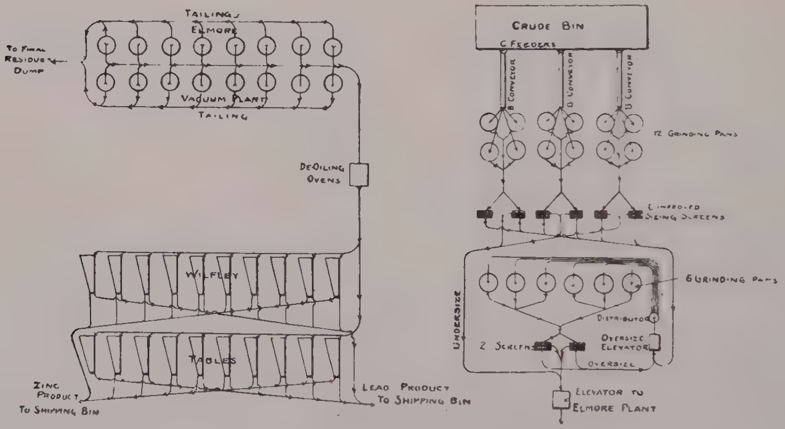


FIG. 33.—Flow-Sheet of Elmore Plant.

The Elmore process has now been discarded for reasons before given, and the Minerals Separation process installed in its place.

EDMUNDIAN COPPER MINE.—The ore at this mine in South Africa consists of chalcopyrite finely disseminated through a felspathic gangue. It is crushed by stone-breakers and Holman pneumatic stamps, and passes direct to a two-unit Elmore plant. The ore assays on the average about 2.5%, and yields a concentrate assaying about 22.5%, with a recovery of 85%.

Garpensberg Mine, Sweden.—The ore consists of a quartzitic gangue with some magnetite carrying chalcopyrite and iron pyrite. The ore, although fairly heavily mineralized with iron pyrite, is of low grade, assaying on the average about 1% copper. The crushing plant consists of a stone-breaker, followed by rolls, the product going to jigs and tables in the ordinary way. The fine tailing, together with the jig tailing after re-crushing in wet ball-mills, is treated in the vacuum machines. One unit of plant was tried first ; later two more were installed, but the plant is now closed.

Traag Mine, Norway.—The ore carries both zinc and lead associated with a heavy gangue. After crushing in stone-breakers and in an Allis-Chalmers Anaconda-type Huntington mill, the pulp is treated on Wilfley tables for the production of a lead concentrate. The tailing from the Wilfley table is passed to a one-unit Elmore plant, which yields a concentrate assaying on the average 58% zinc. The zinc sulphide in the ore is present in the form of a very friable resin blende, and, in consequence of excessive sliming, coupled with heavy gangue, could not be collected by any ordinary water concentration appliances. This plant has now ceased working.

Hadeland Mine, Norway.—The ore consists of blende associated with a large proportion of magnetite and some spathic iron. Trials with various water-concentration appliances had all proved unsatisfactory. The ore is crushed in Krupp ball-mills, and sent direct to the Elmore plant. It yields a high-grade concentrate with a satisfactory extraction. The company, after having operated the one-unit plant for about six months, has ordered additional units.

Telemarken Mine, Norway.—The ore consists of chalcopyrite and bornite in a gangue composed of hornblende, micaceous schist, and hard quartz. The crude ore from the mine is hand-sorted with a view to rejecting some of the waste. The ore thus enriched assays on the average about 4.5% copper. It is crushed in a No. 5 Gates crusher, followed by Ferraris wet ball-mills. The pulp is sent direct to a three-unit Elmore plant, from which a concentrate assaying about 26% copper is obtained, the final tailing containing only 0.20%, thus giving a recovery of about 95% of the total content. Fig. 34 shows a section of the vacuum plant, and Fig. 35 a flow-sheet of the plant at this mine.

Sulitelma Mine, Norway.—The ore carries copper in the form of chalcopyrite associated with a large proportion of iron pyrite, the gangue being micaceous schist. As the ore comes from the mine it is crushed in large stone-breakers, and carefully hand-sorted with a view to selecting clean lump pyrite, which is sold to sulphuric acid works for its sulphur content, the burnt ore

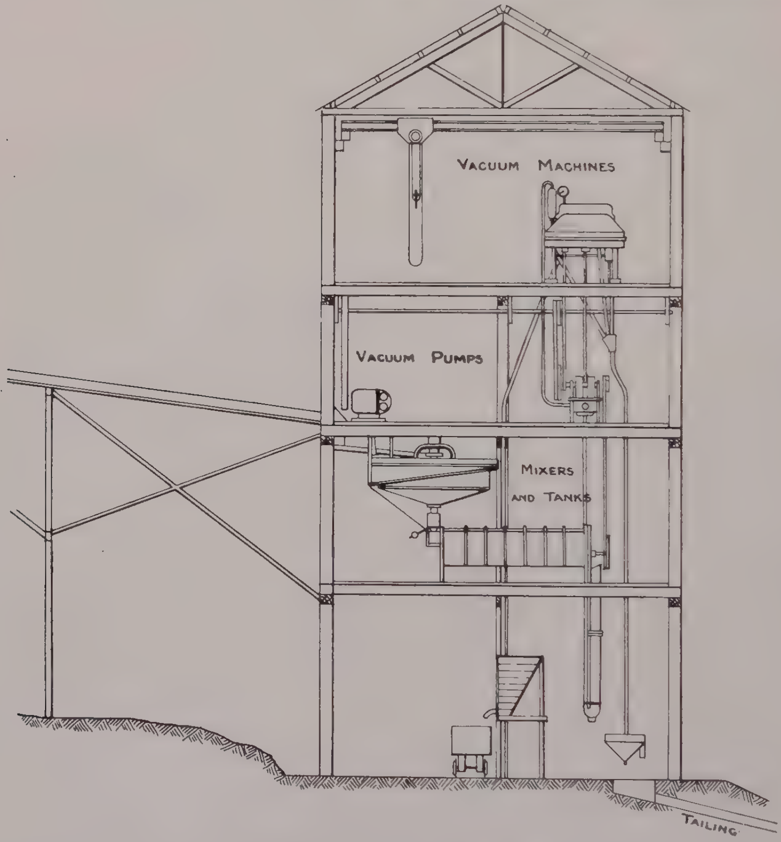
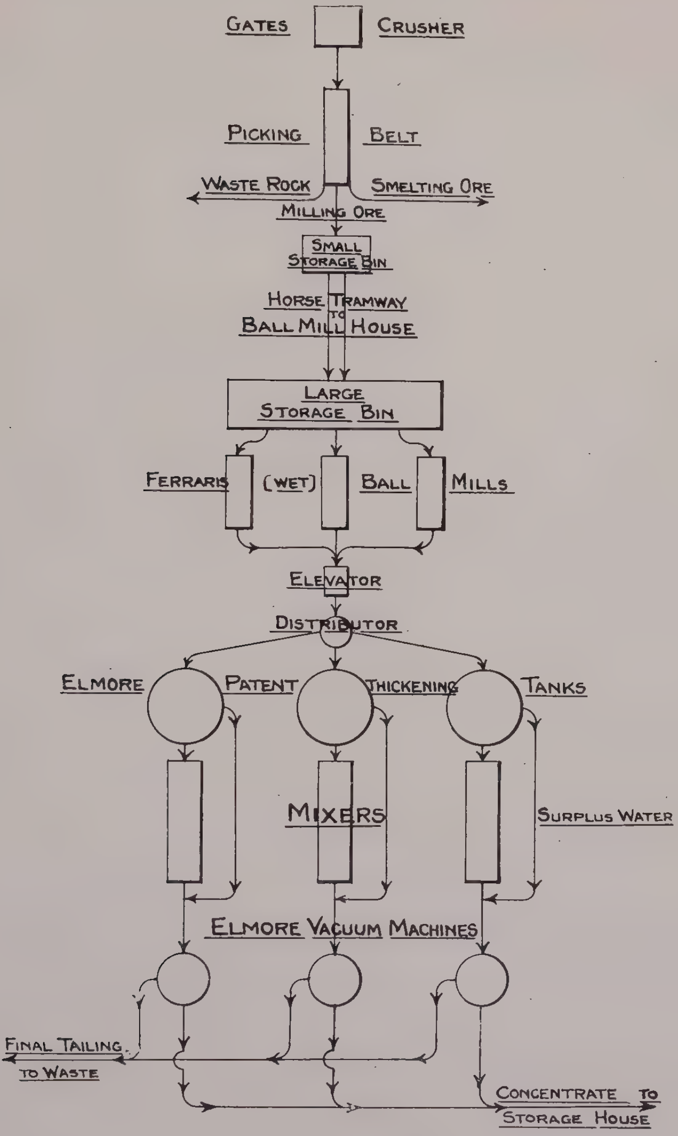


Fig. 34.—Section of Elmore Plant.

being subsequently treated for its copper content. The low-grade ore left after hand-sorting is crushed in rolls and passed to jigs, tables, and vanners. This water-concentration plant is of first-class design, operated with good labour and under excellent technical supervision and control. Nevertheless, the loss of copper in the tailing is heavy, owing to the friable nature of the copper pyrite. The residue from this water-concentration plant



FLOW SHEET

TELEMARKEN MINE, NORWAY.

FIG. 35.

varies in grade from 1% to 1¼% copper, with a quite considerable proportion of iron pyrite and some magnetite. The concentration mill handles about 800 to 900 tons a day, and produces about 500 to 600 tons a day of tailing. This tailing is in the form of an unusually dilute pulp, the proportion of water to solid being probably 100 to 1. At the present time about 400 tons of solid per day with the above proportion of water is sent to the 12-unit Elmore plant for the recovery of the copper mineral. Arrangements are being made which will enable the whole of the 500 to 600 tons of tailing from the water-concentration plant to be sent to the Elmore plant. The small part of the tailing, which is too coarse for treatment direct in the Elmore process, is re-crushed by Heberle ball-mills. The pulp, which, as before stated, is associated with an immense amount of water, is run into large settling-tanks with a view to getting rid of the excess of water before treatment in the Elmore plant. Concentrate varying from 6% up to 11% of copper (the grade depending upon the proportion of iron pyrite) is produced. The final tailing assays on the average 0.2% copper. The great bulk of the material handled by the vacuum machines consists of absolute slime. An average of about 250 tons of concentrate per week is produced from waste material which had previously been discharged direct to the tailing dump. Six additional machines have been delivered to this firm, and will shortly be erected at one of their other mines.

The following table shows the production and grade of the concentrate for the three years ending 31st December, 1913:—

Year ending 31st December.	Tons of Concentrates produced.	Assay of Copper.
1911	6,664	6.46
1912	11,497	6.40
1913	11,472	5.84

The recovery during the period has been over 80%.

The concentrate is practically clean sulphide; it is of low grade in copper, as the process recovers the iron pyrite, which is required by the Sulitelma Company, as well as the copper.

SAXBERGET MINE, SWEDEN.—The ore here is a mixed zinc-lead-silver material, which, after crushing in stone-breakers and wet Grondal ball-mills, is treated on tables for the recovery of the lead. The lead recovery, however, is not good, and consequently the tailing from the tables contains notable proportions of lead and silver in addition to the zinc. Various attempts had been made previously to treat the tailing, without success. The Elmore plant produced a mixed lead-zinc-silver concentrate, which was subsequently smelted in an electrical furnace. Its use has been discontinued and a Minerals Separation plant with a capacity of 125 tons per day is at present in operation.

Other Elmore plants have been installed in several places, but data as to results are not available.

CHAPTER IX.

THE MINERALS SEPARATION PROCESS.

This process represents the joint efforts of Sulman, Picard, and Ballot, and various improvements in processes and apparatus have been added at different times by Froment, Cattermole, Sulman, Picard, Ballot, Higgins, Chapman, Lavers, Greenway, Nutter, Hoover, and others of a large staff. The owner of all these patents is the Minerals Separation, Ltd., a company, the special province of which was intended to be the development of flotation processes. The company licenses the use of the process.

The application of this process to a typical Broken Hill zinkiferous material will be described. This material is the tailing from the lead-concentrating mills after the major part of the lead has been removed by gravity-concentration. Mineralogically, the material has approximately the following composition :

	Per cent.
ZnS	27.1
$ZnSO_4$	2.4
PbS	6.4
$PbSO_4$	1.3
FeS_2	2.5
$MnCO_3$	4.6
$CaCO_3$	3.2
SiO_2	42.4
Total	89.9

The balance of the 100% is made up mostly of garnet and rhodonite and a complex carbonate containing iron, calcium, zinc, and magnesium. The blende is 'black jack' of about the following composition :

	Per cent.
ZnS	81
FeS_2	14
MnS	3

The average assay of the material to be treated by flotation is :

Zinc	14 to 20%
Lead	6%
Silver	7.5 oz. per long ton.

It is necessary to crush this material to about 40-mesh for three reasons : (1) Larger particles float with reluctance ; (2) the sulphides must be freed from the gangue ; (3) crushing has a brightening effect on the sulphide particles.

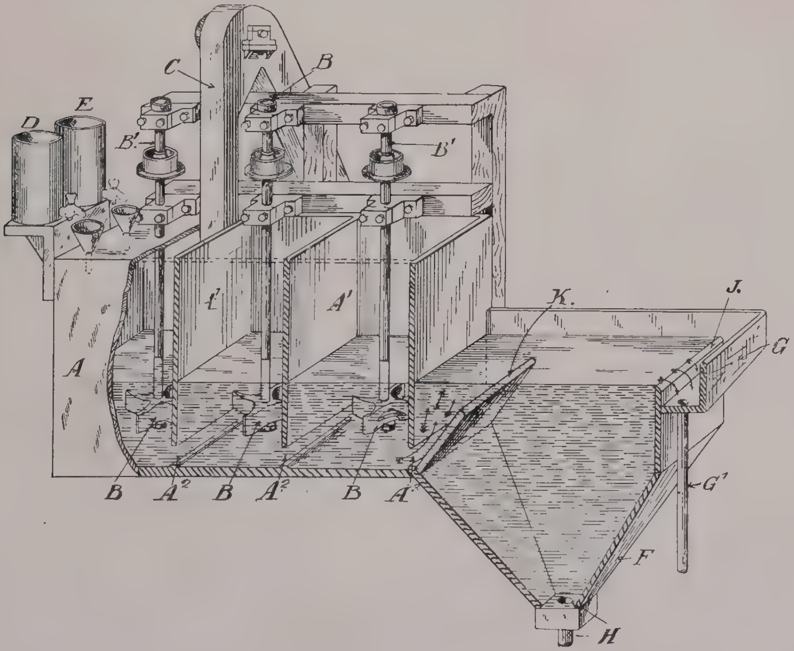


FIG. 36.—Hoover Frothing Machine.

In this process wide limits are permissible as to the amount of slime produced in crushing. A certain amount of slimed sulphides is absolutely essential to the best frothing result ; but there seems no upper limit beyond which fine crushing is deleterious. One plant worked successfully on material 95% of which would pass a 100-mesh screen. After the ore is crushed to the requisite fineness, it is de-watered to a pulp of, as near as may be, three of water to one of ore ; this proportion having been determined by a series of trials extending over several years to be the most likely to produce good results under the other conditions imposed.

After de-watering, the pulp is run into an apparatus designed by the author, and patented for Minerals Separation, Ltd., owners of this process, in British Patent 4911 of 1909. The original form of the apparatus was as in Fig. 36, but several improvements were made later. In order to understand the later form it will be easiest to begin with a description of the original apparatus. This consisted essentially of three mixing and agitating compartments joined to a modified spitzkasten. The three mixing compartments were connected together by apertures A_2 at the bottom of the partitions A_1. These apertures can be of almost any shape as long as the area of the aperture is within certain wide limits. The right-hand mixing compartment is connected with the spitzkasten by the aperture A_3, similar in all respects to the aperture A_2. At J is a horizontal lip, which maintains a water-level, and at H is an outlet, which is of such a size that there will always be an overflow over J. The agitators B are driven by belts or gears, and should travel with a peripheral speed of about 1,200 or 1,300 feet per minute. This will cause the liquid pulp in the compartments to line the sides of the compartment about half-way to the top, and at the centre of the compartment the water-level will be considerably lower than it is in the spitzkasten. Fig. 37 is a longitudinal section of the three mixers and the spitzkasten, and shows the position assumed by the water during operation. At K is a baffle, over which the pulp must flow; the edge of K is a few inches below the water-level J, this distance depending on the size of the plant and other factors, the outside limits being 2 and 8 inches. At D is an apparatus for feeding acid, and at E is an apparatus for feeding oil.

The 3 to 1 pulp is fed into the compartment to the left of Fig. 36 at C, and along with it are fed in also, say, 2lb. of oil and 10lb. of sulphuric acid to the ton of ore. Live steam is also introduced into this compartment through a pipe (not shown), in sufficient quantity to raise the temperature of the pulp to 70° C. Owing to the speed of the agitator these ingredients are thoroughly mixed; in fact, they are churned violently. Large quantities of air are beaten into the pulp. By running the machine for a few minutes on water alone, it will be observed that the quantity of air so beaten into the pulp is enormous, for the clean water will be milk-white. As the inflow of pulp is continuous, the outflow from the left-hand compartment into the middle compartment is also continuous, and of equal volume. In the middle compartment the pulp receives a further violent agitation, and then passes continuously into the right-hand compartment to be agitated once more. From the right-hand compartment the froth emerges through A_3 into the spitzkasten over the baffle K. The rate at which the pulp passes over the baffle K is exactly the same as that at which it is fed at C. As the pulp emerges from A_3 a dense froth, composed of sulphides and bubbles of gas, immediately rises to the surface, where it floats along to J, and passes over into the launder G, and so to the bins. The gangue, on the other hand, does not float, but just manages to get over the baffle K, and then drops to the tip of the spitzkasten, and is removed at H.

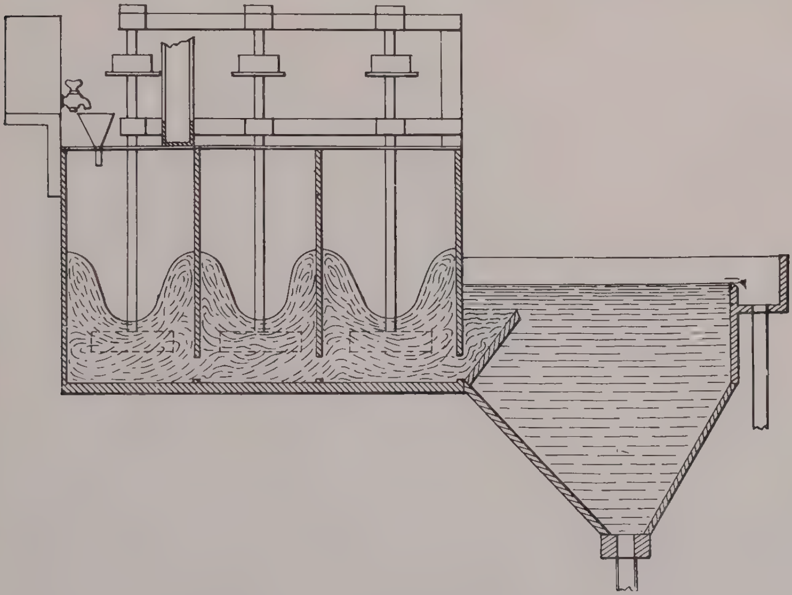


FIG. 37.—Diagram of Water Levels.

A single box of the above description will not give a perfect extraction, and it is necessary to give the pulp a second and a third treatment in a similar box with less agitation. This can be done by simply building three sets like that shown in Fig. 36, and placing them one under the other as in Fig. 38. A set of boxes of this design, with mixing compartments 3 by 3 feet and a spitzkasten 4 by 5 ft., will treat 400 tons of this material per day, and will make something over 150 lb. of clean zinc concentrate per minute.

Instead of placing three sets of this kind one above the other, a much simpler mechanical arrangement can be made which saves

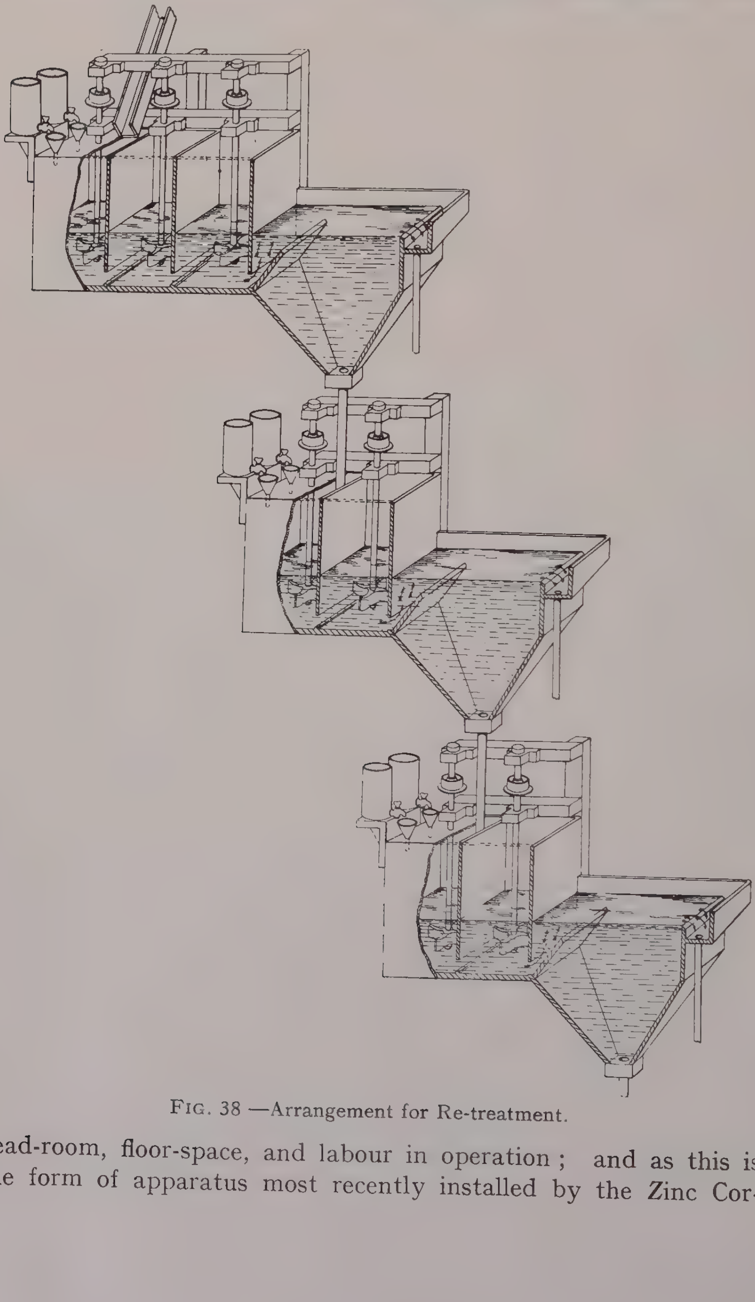
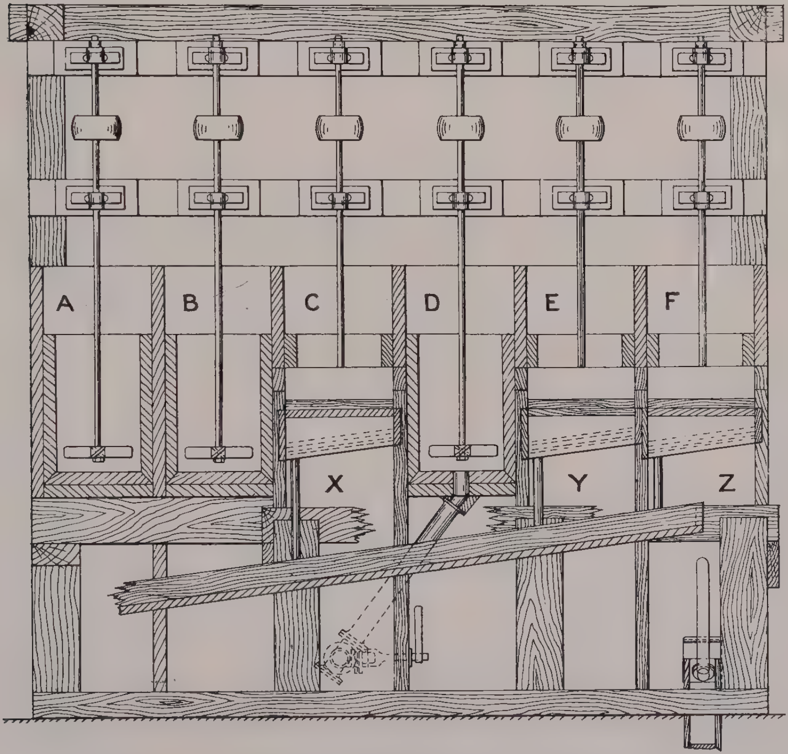


FIG. 38 —Arrangement for Re-treatment.

head-room, floor-space, and labour in operation ; and as this is the form of apparatus most recently installed by the Zinc Corporation, and represents the latest development in the process, it will be described at the risk of some repetition. These ideas were also patented for the Minerals Separation, Ltd.

This arrangement of plant makes use of the centrifugal effect of the agitators, and uses them partly as pumps. Referring to Figs. 39, 40, and 41, which are elevation, plan, and section of the latest arrangement, A, B, C, D, E, and F are mixing compartments, each containing an agitator running at high speed; X, Y, and Z are spitzkastens. The ore, water, oil, acid, and steam are fed into the compartment A in proper proportions, where the pulp is thoroughly mixed and violently agitated; A has a hole at the bottom, which allows the pulp to pass into B, where there is more violent agitation; B has a hole in the bottom, which allows the



FRONT ELEVATION.

FIG. 39.—Hoover Single-Level Apparatus.

pulp to pass into C, and from C it goes over a baffle into the spitzkasten X, where a heavy, dense mineral froth is floated over the lip of X; the gangue, along with some of the sulphides, passes to the tip of the spitzkasten X, the tip being connected by a pipe M with the bottom of D. The agitator in compartment D acts as a centrifugal pump, and draws the material from the tip of X up into compartment D, where the pulp receives further agitation and aeration. The lift required of this pump is very slight, for it will be observed that there is one liquid level throughout the whole of this combined arrangement; the agitator-pump in D has to pump against a head which is practically only the friction head of the system. From D the pulp passes to E, where further aeration by agitation is given; from E the pulp passes over a baffle into the spitzkasten Y, the froth flowing over the lip of Y and the gangue with a little remaining sulphide dropping down to the tip of Y; the tip of Y is connected by a pipe N with the bottom of the mixing compartment F, and the agitator in F acts

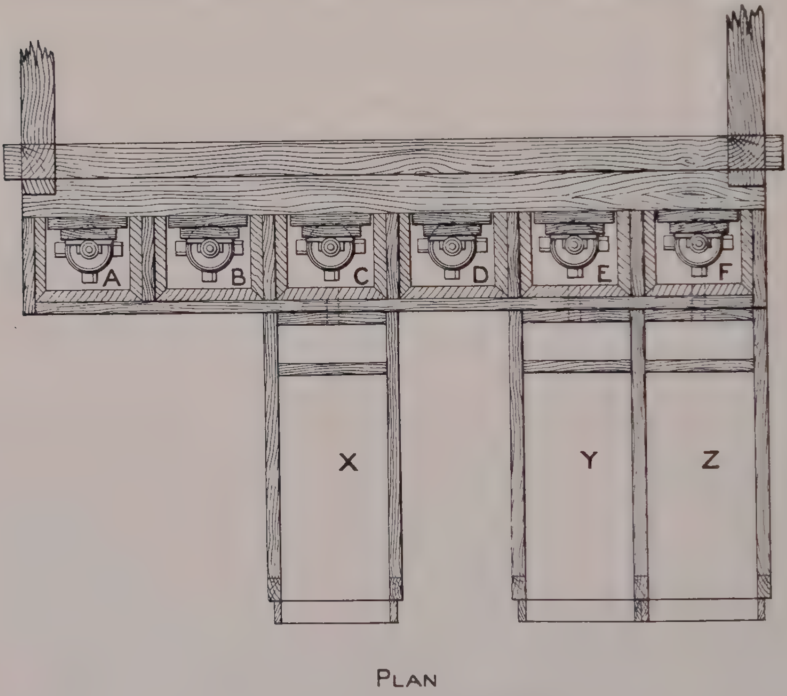
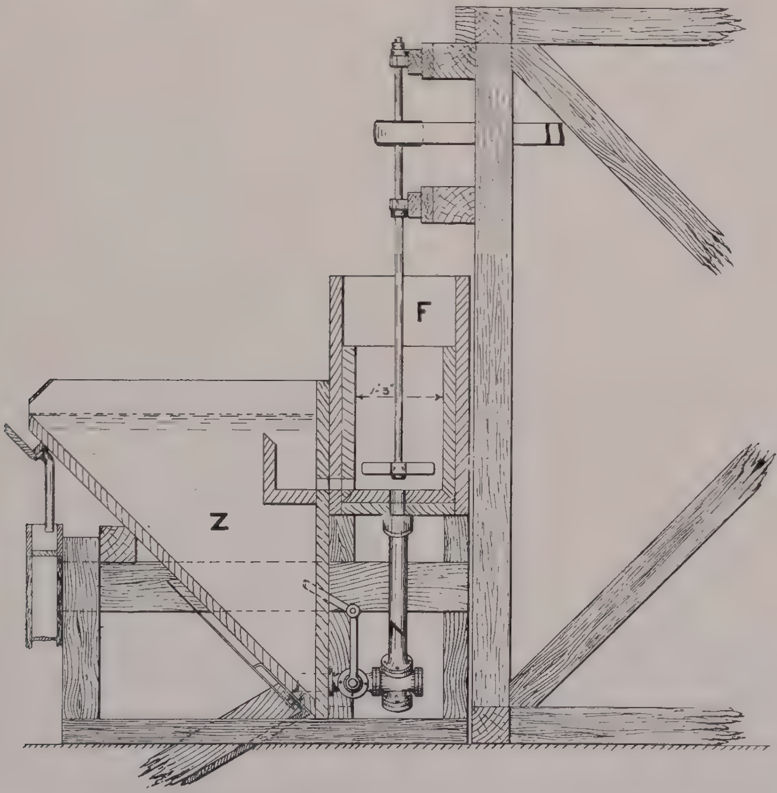


FIG. 40.—Hoover Single-Level Apparatus.

as a pump to draw the pulp up into F. Here the head on the pump is only the friction head, and as in the case of M, N is also the suction side of the centrifugal pump. The pulp gets further agitation in the mixing compartment F, and finally emerges over a baffle into the spitzkasten *Z*, where the last available mineral froth passes over the lip, and the gangue drops down to the tip, from whence it is drawn through a regulated opening and passes to the tailing flume. A perspective drawing of this plant is also shown in Fig. 42, which may help to explain the scheme.



— SIDE ELEVATION. —

FIG. 41.—Hoover Single-Level Apparatus.

This plant has the merit of extreme compactness. One unit of a capacity of 400 tons per day would occupy a floor space of less than 30 by 10ft., and be less than 12ft. in height. The whole operation is in front of one man, and the labour required is so reduced to a minimum. By placing two units front to front, one operator could watch the treatment of 1,000 tons per day. These agitators take 5 h.p. each of a plant of a capacity of 400 tons per day, and on most ores six agitators would be ample. Some ore would probably require that the agitators be arranged thus: first a set of three followed by a spitzkasten; then a set of two followed by a spitzkasten; and lastly, one agitator followed by a spitzkasten. Other forms consist of one agitator for each of eight spitzkastens, and variations of connections in each case depending on the nature of the ore.

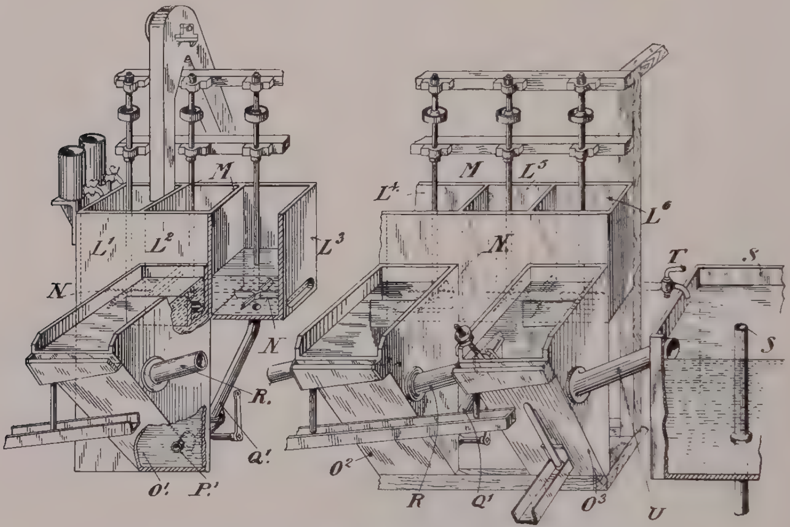


FIG. 42.—Hoover Single-Level Apparatus.

In most flotation plants, whether using this process or the others previously described, it will be found of decided advantage to use the water over and over again, as there is some latent acidity always in solution after the flotation is complete, and besides, the salts in solution have a beneficial coagulating effect. If the salts in solution increase to beyond 4,000 grains per gallon, the millmen have acquired the idea that it has a detrimental effect on the flotation, but this does not seem to be based entirely on sound reasoning; the detrimental effect is probably an indirect result of salts in solution, and could be obviated by proper manipulation.

One of the recent improvements in this process is by way of using as a froth-producing agent a soluble substance to replace the insoluble oil formerly used. The soluble substances which are available for this purpose are: Alcohols, especially amyl alcohol and some of its soluble salts, such as amyl acetate; all the phenols and their near derivatives; the turpentines and many of the products from the destructive distillation of wood; most of the essential oils, and especially the oil from *eucalyptus amygdalena*, one of the most common eucalyptus in Australia. This last is probably the best of all, and as the quantity used is less than a pound per ton of ore, the high price of the oil does not hinder its use. One decided advantage of using these soluble frothing agents is that where a subsequent treatment of the concentrate is desired for the separation of lead and zinc sulphides, it can be treated directly on tables. Where an insoluble oil was formerly used it was necessary to burn this insoluble oil, as it made the sulphides gummy, and they could scarcely be separated by gravity.

The following figures give the dimensions of units of various sizes. Part of this information has been derived from actual observation, and part is deduced from the known behaviour of the process under given conditions. No doubt further work with the process will modify the ideas as to size, even if the form is maintained as at present.

Estimated daily capacity.		Tons. 50–60	Tons. 100	Tons. 200	Tons. 300	Tons. 500
Agitators	Number	6	6	6	6	6
Right and left	Diameter, inches ...	12	14	16	18	24
	Height of web, inches	2	2	2¼	2½	4
Agitator	Number	6	6	6	6	6
	Diameter, inches ...	1¼	1⅝	1¾	2	2¼
	r.p.m.	440	380	335	300	225
Mixing boxes	Number	6	6	6	6	6
	Width, inches ...	16	18	22	25	36
	Depth, inches ...	36	40	37	43½	54
Spitzkastens	Number	3	3	3	3	3
	Width, inches ...	16	18	22	25	36
	Depth, inches ...	51	58	62	62½	78
	Length, inches ...	39	42	45	48	54
Openings from Mixers to Spitzkastens	Number	3	3	3	3	3
		One into each spitzkasten.				
	Dimensions, sq. in. ...	18	25	32	36	48
	Height above floor of mixer, inches ...	2	2	2	2	2
Main driving-shaft	Number	1	1	1	1	1
	Diameter, inches ...	1½	2	2½	2½	2¾
	Speed	288	250	220	96	363
Driving-shaft pulleys	Number	6	6	6	6	6
	Diameter, inches ...	12	16	20	24	32
	Width, inches ...	4½	6	6½	9	11
Return pipes from Spitz to next mixer	Number	4	4	4	4	4
	Diameter, inches ...	2	2¼	3	3¼	4

A further improvement to this apparatus, that eliminates all pipes, pumps, and valves, and makes the process practically independent of the operator, is illustrated below. The apparatus and its application to flotation processes will be sufficiently clear from the following descriptions, and Figs. 43, 44, and 45, which are elevation, plan, and section of the new machine:

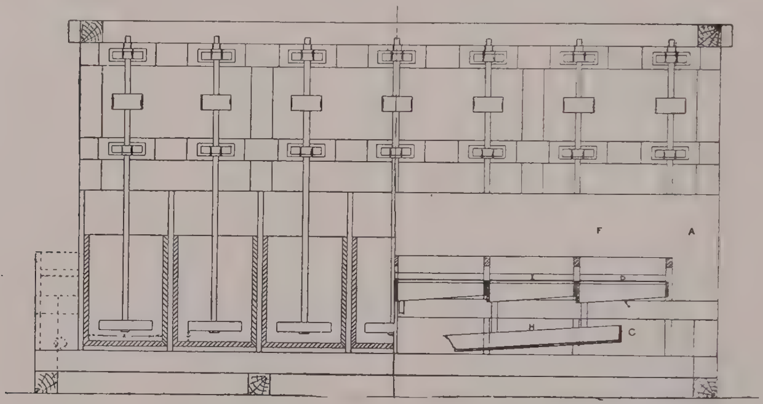


FIG. 43.—Elevation Hoover Valveless Apparatus.

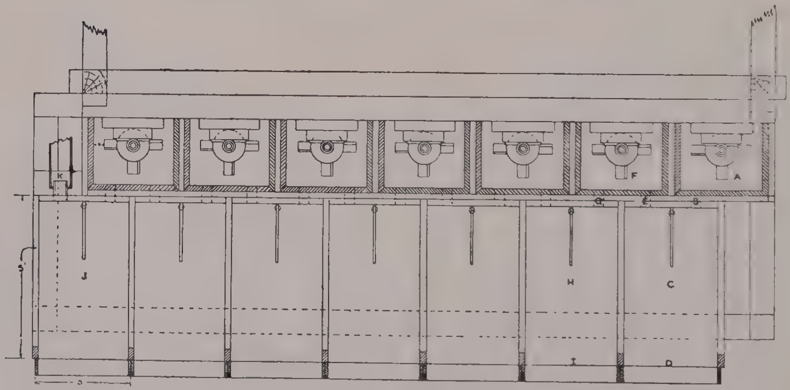


FIG. 44.—Plan Hoover Valveless Apparatus.

The ore is fed in at A (Figs. 44 and 45), along with water, oil, and acid, and after a period of agitation and mixing, emerges at the opening B into the flotation-box C. A portion of the sulphide floats and is removed at the lip D. The remainder of the sulphide, with the gangue, etc., is drawn through the hole E into the mixing-compartment F, whence, after further agitation, it is discharged from the hole G into the flotation-box H, where more floating sulphides are removed at the lip I, and so on through the whole series, alternately agitating and taking off a froth, until the last frothing-box J, where the gangue-sand, fully depleted of sulphides, is withdrawn at the valve K. The agitators in the mixing-compartments should run at a peripheral speed of about 1,500 linear feet per minute.

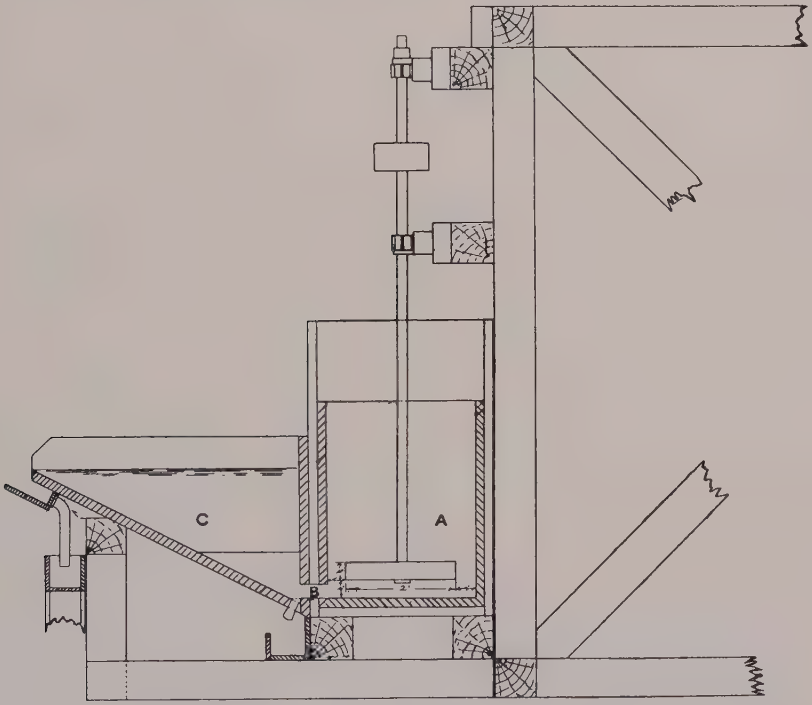


FIG. 45.—Section Hoover Valveless Apparatus.

Another form of apparatus which has many advantages of simplicity is shown in Figs. 46, 47, and 48. In this case the pulp moves in a straight line through the whole series, receiving successive agitations at A, A, A, and yielding froths at B, B, B, which froths are drawn off at the lips D, D, D. At C are a valve and a pipe which regulate the outflow of the tailing and the height of water in the whole series. The agitators in the mixing-compartments A, A, A should run at a peripheral speed of about 1,500 linear feet per minute. In B, B, B there are slow-moving agitators to keep the sand slowly in motion; these should run at 10 to 20 r.p.m., but not fast enough to break the surface of the water. On some ores the agitators may not be needed in B, B, B, etc.

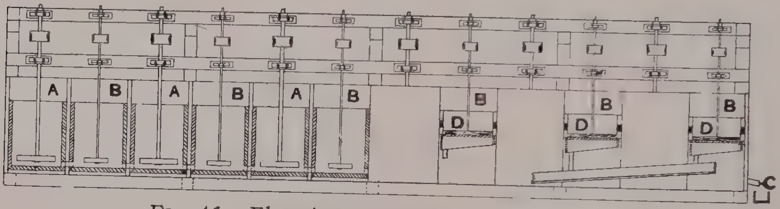


FIG. 46.—Elevation Hoover Valveless Apparatus.

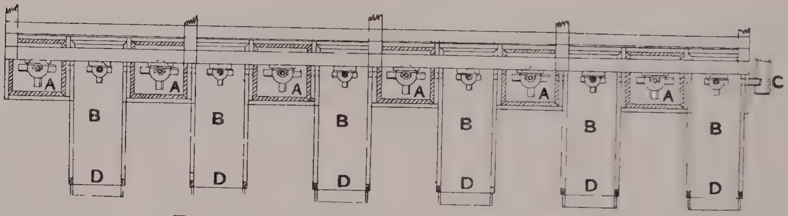


FIG. 47.—Plan Hoover Valveless Apparatus.

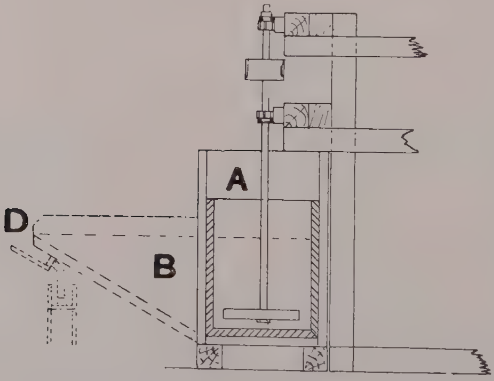


FIG. 48.—Section Hoover Valveless Apparatus.

OLD GRANULATION PLANT.

The first mention of the Minerals Separation process is in the Annual Report for the Department of Mines of New South Wales for 1904, where it is recorded that the Sulphide Corporation had been experimenting with an oleaginous process, and that a plant would be erected in the following year. In 1905 the process was described as being one either where the mineral was coagulated and sunk, or where a small amount of oil was used to make the mineral float. At this plant the patents of the company had their first practical application. During 1905 the Cattermole idea was abandoned, and the plant was altered to a flotation-process plant, and operated as successfully as could be expected in a plant which had undergone so many vicissitudes. The work here in 1907 served as a model for the Zinc Corporation in their first trial of the Minerals Separation process, but they were not able to duplicate the results, and therefore abandoned the Minerals Separation, and installed the Elmore process. The plant continued operations during 1907, but was finally closed in 1908. The material treated was typical Broken Hill dump-tailing from the lead-concentrating mills, and the three years' operations are here shown.

	FEED				CONCENTRATE						
		ASSAY				ASSAY			RECOVERY		
YEAR	Tons	Zn %	Pb %	Ag Oz	Tons	Zn %	Pb %	Ag Oz	Zn %	Pb %	Ag %
1906	23,709	20.4	6.4	7.4	8,013	44.0	11.8	14.8	72.8	62.1	67.3
1907	65,705	21.0	5.6	7.0	20,621	45.2	9.7	13.4	67.7	54.2	60.7
1908	46,394	20.4	5.6	7.0	16,513	45.1	9.5	13.8	78.7	60.0	69.6

This plant at periods gave much better results than the average, and subsequent work elsewhere with the process justified the confidence of the engineers in its merit.

SLIME PLANT, CENTRAL MINE.

In 1906 the Minerals Separation, Ltd., purchased from the Block 10 company 60,000 tons of high-grade slime, and began the erection of a plant to treat this sort of material on a joint arrangement with the Sulphide Corporation, which company had large dumps of the same sort. This venture was one of the most interesting in the history of the application of flotation processes. The material treated is practically all finer than 100-mesh, and 82% was finer than 200-mesh. The plant was built in 1907, and it was originally intended to re-treat the flotation-concentrate on tables, and separate the lead sulphide from the zinc sulphide. This re-treatment scheme failed, however, and there being at that time no market for the mixed concentrate, the plant was shut down. During 1909 there was some demand for the mixed product on the part of zinc buyers and for experimental smelting* work on mixed sulphides, and the plant was run for a time. In 1910 a market was opened in Norway for mixed lead-zinc concentrate, and the plant was operated long enough to fill a contract. The three years' operations are shown in the following table :

	FEED				CONCENTRATE						
		ASSAY				ASSAY			RECOVERIES		
YEAR	Tons	Zn %	Pb %	Ag Oz	Tons	Zn %	Pb %	Ag Oz	Zn %	Pb %	Ag %
1908	4,382	20.9	17.9	17.2	1,912	25.0	26.0	33.1	69.1	62.9	63.6
1909	2,179	19.7	16.8	19.3	1,109	32.5	21.4	28.2	84.0	64.7	74.6
1910	18,395	20.7	17.6	20.8	10,164	32.2	22.4	29.6	85.8	70.5	78.6

It is safe to say that such excellent recoveries on such a slimy material in a concentrate practically pure sulphide were never before secured by any form of mechanical concentration.

NEW MILL, CENTRAL MINE.

During 1906 there was under construction a new concentrating mill on the Central mine at Broken Hill, which was so designed that it should receive the ore by bucket-tramway from the mine, and turn out finished lead concentrate from the lead section ; and then, taking the tailing from the lead section, treat it by the Minerals Separation process, and produce finished zinc concentrate, all in one continuous operation.† Two units of the Minerals Separation process of the old type were installed in the zinc section, and the plant started in 1907. Fig. 49 is a flow-sheet of this plant. In 1908 the plant operated continuously with good results, although the concentrate produced from this plant was not of so high a tenor in zinc as the other plants, because of the high iron sulphide content of the ore, and also, perhaps, because some of the gangue minerals have a greater tendency to float when freshly crushed than after they have lain in the dumps for some time. In 1910 alterations in the type of machine were made, and mixing and frothing boxes of the type described in the beginning of this chapter were installed. The capacity of the plant was thereby increased. The tailing is taken from the lead section with all the mill water, and is first drained on a belt, and then the slime goes

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***Engineering & Mining Journal*, Vol. xc., 1910, August 13, p. 323–324.

† 'Annual Report for the Department of Mines of New South Wales for 1906' p. 89.

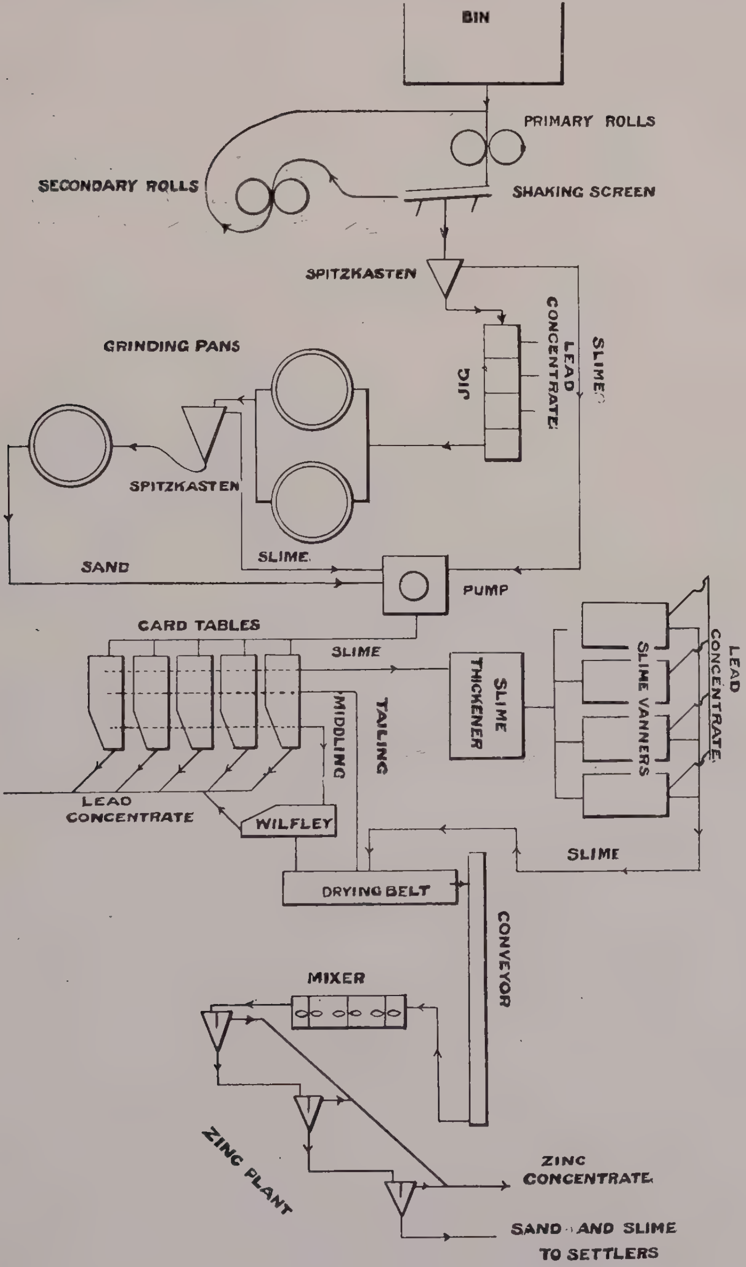

FIG. 49.—Flow-Sheet Central Mine Plant.

to tanks to settle. From the tanks and the draining-belt the material is fed by belt-conveyors to the flotation section, where the treatment is as previously described. No crushing is required, as the material is sufficiently fine from the lead operations.

Fig. 50 is a photograph of the dump. The results of the four years' work are given in the following table. The columns showing the zinc content of the concentrate and the recovery columns are a fine study in persistence. It was difficult to account for the grade of concentrate being low in this plant for the first two years. The table shows the improvement.

FIG. 50.—Tailing Heap of Central Mine.

		FEED				CONCENTRATE					
			ASSAY				ASSAY			RECOVERY	
YEAR	Tons	Zn %	Pb %	Ag Oz	Tons	Zn %	Pb %	Ag Oz	Zn %	Pb %	Ag %
1906-7	28,275	19.3	6.3	8.6	6,894	36.9	12.6	15.1	46.5	49.3	42.5
1907-8	157,142	20.5	6.1	9.1	54,842	40.4	13.1	17.7	68.9	75.7	67.6
1908-9	157,907	21.4	6.0	8.6	67,981	42.5	11.4	16.6	85.5	82.5	83.8
1909-10	227,126	20.7	6.1	6.8	88,767	43.5	11.2	14.0	82.2	72.0	80.5
1910-11	186,070	19.3	5.6	7.1	71,667	42.7	10.9	14.7	85.4	74.8	80.1
1911-12					69,326	46.3	8.7	16.0			

Several thousand tons of slime from the dumps have been treated in this plant, in addition to the slime in the material coming from the lead mill. In July, 1911, a re-treatment section was started; and, in addition to the zinc concentrate produced in the last year, there were recovered from the lead-mill tailing 2,941 tons of lead concentrate assaying 48.1oz. silver and 61.4% lead.

MINERALS SEPARATION, LTD.

In 1906 this company bought a large dump of lead-mill tailing from the Sulphide Corporation, and during 1907 a plant was constructed.* Profiting by lessons learned from earlier experiences, this mill did good work from the start, and has treated nearly 560,000 tons of dump material assaying 20% zinc, 6.2% lead, and 5.9oz. silver, and produced 218,000 tons of concentrate assaying 47.3% zinc, 9.8% lead, and 11oz. silver. No re-treatment of the concentrate is given in this plant. The cost in this plant over a typical period was as follows :

	s.	d.
Tramming		6.48
Crushing	1	8.45
Flotation	4	5.84
Disposal of concentrate		6.62
,, tailing		4.46
Total	7	7.85

Of these items the one for 'flotation' is of chief interest, and is made up as follows :

	s.	d.
Power		5.47
Acid	1	0.13
Oil		6.48
Supplies		5.18
Labour and salaries		3.06
Fuel for heating		5.16
Assays		1.22
Water		3.20
Repairs (labour and supplies) ..		6.31
General expense		5.63
Total	4	5.84

ZINC CORPORATION, LTD.

This company tried the Minerals Separation process in 1907, after abandoning the Potter process. The Minerals Separation process was rejected in turn, and the Elmore process installed, which latter process was used successfully for two years, when the

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***Engineering & Mining Journal*, April 30, 1910, p. 913, 'Oil Process at Broken Hill'.

Minerals Separation process was again adopted at the beginning of 1911. The Minerals Separation process had shortly before this time been considerably improved as regards its mechanical operation, and had demonstrated its adaptability to the slimiest material.

The cost for a typical period is as follows :

	s.	d.
Tramming	1	4.78
Grinding	1	3.41
Flotation	4	3.79
Re-concentration		8.97
Handling concentrate		4.94
Handling tailing		4.13
General expenses		8.72
Total	9	2.74

Of these figures the one for 'flotation' is of chief interest, and is made up as follows :

	s.	d.
Power		1.74
Acid		9.10
Oil		6.00
Supplies		3.50
Labour and salaries		2.22
Fuel for heating		5.42
Assays		0.30
Water		1.50
Repairs		8.90
Royalty	1	1.11
General expense (half)		4.36
Total	4	8.15

In all the company owns 27 dumps, most of which are either of a refractory nature, or are slime dumps ; and, seeing that all have to be removed by a given time, it is necessary to take a certain amount from each.

The cheapest and easiest way of removing these dumps is an important problem. At first sight a mechanical means of handling the tailing suggests itself, but as only a small portion of the daily tonnage treated is taken from each dump, it would never pay to incur a heavy capital expenditure on a mechanism which would be worked considerably under its capacity. As these dumps are scattered over a large area, extending from the north to the south end of the Broken Hill district, the material is hauled (with the exception of the South mine tailing-dumps, which have been equipped with an aerial tram) by the Silverton Tramway Company in its railway trucks. A tram-track is laid into each of the dumps, and at a height a little above the top of the truck a loading gantry or staging is erected; this staging is hinged on the dump side of the track, and can be lifted by means of a small block and tackle to allow the locomotive to pass. The trucks supplied by the Silverton Tramway Company are strong iron cars of the box type, 15-ton capacity, 15ft. by 7ft. 6in., with doors at each side opening in the centre about half the length of the side, leaving a quarter standing vertical at each end. These trucks are certainly not the most suitable type, and entail much labour to empty, all of which has to be done by shovelling. A gang of men (the transport gang) are kept constantly employed at this class of work; and, in addition, they unload all coal, mine stores, etc. As the dumps are so scattered, the company is compelled to lay quite a quantity of tracks both to the dumps and at the works, which at the present time amounts to 22,000ft. The tramway company has set (subject to approval) a time-table each week, stating the number of trucks required from each dump, and the time suitable to both parties, namely, the contractor loading and the tramway company sending the empty trucks to each dump to be filled. The trucks, on arrival at the works, pass over a Pooley weighbridge, capable of weighing 40 tons, and after being weighed and then sampled for assay and moisture, the tailing is emptied into two storage-bins, having a total storage capacity of 1,888 tons (No. 1, 666 tons; No. 2, 1,222 tons). These bins are excavated out of the ground and made of concrete. At the bottom of the bins are openings, which deliver to 16 Challenge feeders (size of table, 2ft. 6in. diam., 15 r.p.m.). No. 1 bin has 10 feeders; No. 2, 6 feeders. By means of the Challenge feeders the millman is able, to some extent, to mix the material from the various dumps. The Challenge feeders deliver to a conveyor-belt, one to each bin parallel to it, and these again deliver to another conveyor-belt at right angles to the bin conveyors, which conveys the tailing up the hill, first to a rubbish trommel (8ft. 6in by 4ft. by 2ft. 6in., 21 r.p.m.) clothed with a punched plate, having 2in. holes; this trommel is for the purpose of removing any stones, large chips, and lumps of slime, or any large size material that would interfere with the feeding arrangements from the mill bins, or which would be too coarse to enter the tube-mill feed-pipes, and so cause serious chokage. The product through the trommel passes to another conveyor, No. 4, 24in. wide. troughed 6in., running 363ft. per minute, and then to another conveyor running at right angles to these over the top of the bins. This belt is fitted with an automatic Robins distributor or take-off, which distributes the material evenly over the bins, and is of great assistance in mixing the material.

The following is a statement giving classification tests, assays, and metal content of the feed to the crushing section, for the three months ended December 31, 1911:

		Percentage Weight.	ASSAYS.			Percent. metal distribution.		
			Zn.%	Ag. oz.	Pb %	Zn	Ag	Pb
Original		100	16.4	7.7	7.0	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	37.7	14.1	7.4	7.9	32.4	36.2	42.5
,, 100	,, 0.16	35.4	16.7	5.7	5.3	36.0	26.2	26.8
,, 150	,, 0.09	8.9	17.8	6.8	5.6	9.6	7.9	7.1
,, 200	,, 0.06	2.8	19.9	8.0	5.0	3.4	2.9	2.0
Thro' 200	0.06 to 0	15.2	19.9	13.2	10.7	18.4	26.0	23.2

All assay figures are in terms of total metals; dry screening done on Hoover laboratory sizer.

From the mill bins, which have a total capacity of 874 tons, the material is automatically fed by means of four Challenge feeders (2ft. 6in.), running at 6.25 r.p.m. to chutes leading to three elevators of 16in. by 8-ply Balata belting, travelling 380ft. per minute. These elevators deliver to six revolving screens clothed with brass woven wire, 12 by 12 mesh and 21 gauge; the over-size goes to the tube-mills, and the through product, which needs further grinding, to eight grinding pans, which are fitted with Freeman classifier pipes.

The discharge from the tube-mills (size of mill approximately 10 by 5ft., lined with ribbed liners, running at 24 r.p.m.), together with the material from the pans, runs to a Callow settler 8ft. diam. by 9ft. deep, fitted with annular overflow, for thickening; the overflow from this settler runs to four more 8ft. Callow settlers for de-watering, the clear water returning into circuit, while the thickened slimy product runs through a small spigot, and unites with the thickened pulp coming from the single settler first mentioned; then to an elevator (size 16in., 8-ply, 300ft. per min.), which delivers to the mixer-box for flotation.

The following table gives the details of the material after crushing, showing classification tests, assays, and percentage metal distribution of the feed to the flotation plant, for the three months ended December 31, 1911:

		Percentage Weight.	ASSAYS.			Percent. metal distribution		
			Zn. %	Ag. oz.	Pb %	Zn	Ag	Pb
Original		100	16.4	7.7	7.0	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	2.2	10.3	4.6	3.0	1.4	1.3	0.9
,, 100	,, 0.16	38.6	15.3	4.8	3.9	36.0	24.1	21.5
,, 150	,, 0.09	16.6	17.2	6.7	5.9	17.4	14.4	14.0
,, 200	,, 0.06	6.9	18.6	7.6	5.8	7.8	6.6	5.7
Thro' 200	0.06 to 0	35.7	17.7	11.6	11.6	38.5	53.8	59.1

All assay figures are in terms of total metals; dry screening on a Hoover laboratory sizer.

The mixer-box is divided into 16 compartments, eight of which are for mixing and eight for flotation; the mixing is done in each of the compartments (3ft. square) by means of an impeller or paddle, 2ft. diam., working horizontally on a vertical shaft, having a speed of 306 r.p.m. From the mixer-box to the flotation-box there is an opening, 14 by 4in. and 12½in. from the bottom of the box, as an outlet from the mixer-box to the flotation compartment.

At No. 1 mixer-box the acid solution, the eucalyptus oil, and the steam for heating are added. The feed running into No. 1 mixer-box receives a certain amount of agitation by means of the horizontal impeller before it passes into No. 1 flotation compartment. The feed, being mixed with the acid and oil, becomes emulsified, and causes immediate flotation of a fair proportion of the sulphide particles, which flow over the lip of the flotation compartment into a launder. The rest of the material which has not been lifted falls to the bottom of the flotation compartment, and from there it is drawn by means of No. 2 impeller into No. 2 mixer-box through a 5in. pipe, and after receiving a certain amount of agitation and aeration it is forced into No. 2 flotation compartment, and a further amount of sulphides is floated off into the launder. This zig-zag track is continued through the length of the mixer-box until it reaches the last flotation compartment, and by that time all the free sulphides should be removed; there only remains the residue, which is removed by opening a valve at the bottom of the last flotation compartment. This valve regulates the whole of the flow through the boxes, and has to be adjusted according to the proportion of water to feed, which is 3.5 of water to 1 of tailing by weight.

The following is a statement showing classification tests, assays, and percentage metal distribution of the flotation concentrate, for three months ended December 31, 1911:

		Percentage Weight.	ASSAYS.			Percent. metal extraction		
			Zn. %	Ag. oz.	Pb %	Zn	Ag	Pb
Original		100	41.8	15.3	12.1	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	1.7	47.1	11.4	6.0	1.9	1.3	0.8
,, 100	,, 0.16	46.9	43.8	11.3	9.0	49.1	34.6	34.9
,, 150	,, 0.09	13.9	41.7	13.5	11.3	13.9	12.3	13.0
,, 200	,, 0.06	4.2	43.3	15.3	11.1	4.4	4.2	3.9
Thro' 200	0.06 to 0	33.3	38.8	21.9	17.1	30.9	47.7	47.1

All assay figures are in terms of total metals; dry screening on a Hoover laboratory sizer.

Sectional samples taken from each of the flotation compartments, when overflowing at the lips, are very interesting, as will be seen by referring to the following table:

SECTIONAL SAMPLING OF M.S. FLOTATION-BOXES FOR PERIOD JANUARY 30 TO FEBRUARY 13, 1912.

	ASSAYS.	Total Metals.		Oxidized Metals.		Insoluble.
	Zn. %	Ag. %	Pb %	Zn. %	Pb. %	%
No. 1 Box ..	38.6	31.9	17.3	0.4	2.8	6.3
,, 2 ,, ..	43.7	21.1	13.7	0.4	2.4	2.7
,, 3 ,, ..	46.1	17.1	11.2	0.3	2.1	2.2
,, 4 ,, ..	46.1	15.7	10.6	0.3	2.3	2.5
,, 5 ,, ..	44.8	15.1	10.6	0.4	2.8	4.1
,, 6 ,, ..	41.4	15.8	11.6	0.4	3.7	7.0
,, 7 ,, ..	39.3	15.7	12.4	0.4	4.0	9.0
,, 8 ,, ..	32.4	15.0	13.8	0.6	5.1	17.3

No. 1 compartment contained a high percentage of lead, and also of insoluble matter, and it was found that 7 and 8 also contained such a high percentage of insoluble matter that it was necessary to return these to No. 1 mixer-box again for re-flotation, with beneficial results. If was found, however, that, in spite of all the precautions, a high percentage of insoluble matter came over with the float, with certain ores, particularly those containing granular garnet. It is difficult to obtain a high-grade final zinc concentrate from these ores, although they are easily floated, requiring very little acid and oil. With the object of further raising the grade, it was decided to re-float the whole of the concentrate obtained from the first two units of the plant, by passing it into a third flotation unit. The results obtained by re-floating the whole of the flotation concentrate from the two units have been very satisfactory, and can easily account for about a 2% rise in the zinc content of the ultimate flotation concentrate. At the time of writing the results obtained from a 14.8% zinc feed are approximately 42% zinc flotation, 44% re-flotation, and 46.5% finished zinc from the de-leading plant.

The following statement shows classification tests, assays, and percentage metal distribution of the re-flotation concentrate, for two months ended December 31, 1911 :

		Percentage	ASSAYS.			Percent. metal distribution		
		Weight.	Zn.%	Ag. oz.	Pb %	Zn	Ag	Pb
Original		100	43.2	15.7	12.2	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	1.3	45.1	12.0	6.7	1.4	1.0	0.7
,, 100	,, 0.16	42.1	46.5	10.7	8.5	45.3	28.7	29.3
,, 150	,, 0.09	11.7	43.4	13.0	11.0	11.7	9.7	10.5
,, 200	,, 0.06	4.6	44.2	15.1	10.3	4.7	4.4	3.9
Thro' 200	0.06 to 0	40.3	39.8	22.1	17.0	37.1	56.7	56.2

All assays are in terms of total metals ; dry screening on a Hoover laboratory sizer.

The following statement shows classification tests, assays, and percentage metal distribution of sand-residue, for three months ended December 31, 1911 :

		Percentage Weight.	ASSAYS.			Percent. metal distribution		
			Zn.%	Ag.%	Pb %	Zn	Ag	Pb
Original		100	2.4	2.7	4.3	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	9.5	4.9	3.3	3.4	19.4	11.6	7.5
,, 100	,, 0.16	51.1	2.2	2.2	3.1	46.8	41.6	36.8
,, 150	,, 0.09	12.1	1.7	2.2	3.7	8.6	9.9	10.4
,, 200	,, 0.06	4.0	1.6	2.9	3.9	2.7	4.3	3.6
Thro' 200	0.06 to 0	23.3	2.4	3.9	7.5	23.3	33.7	41.0

All assay figures are in terms of total metals; dry screening on a Hoover laboratory sizer.

The following statement shows classification tests, assays, and percentage metal distribution of re-flotation residue, for three months ended December 31, 1911 :—

		Percentage Weight.	ASSAYS.			Percent. metal distribution		
			Zn.%	Ag. oz.	Pb. %	Zn	Ag	Pb
Original		100	33.6	13.6	13.4	100	100	100
Mesh.	Aperture.							
On 40	On 0.5	2.9	45.8	7.3	5.4	4.0	1.6	1.2
,, 100	,, 0.16	52.2	36.8	10.0	10.8	57.2	38.4	42.1
,, 150	,, 0.09	13.1	29.6	14.1	14.6	11.5	13.6	14.3
,, 200	,, 0.06	5.2	32.7	15.5	14.0	5.1	5.9	5.4
Thro' 200	0.06 to 0	26.6	27.6	20.9	18.7	21.9	40.9	37.1

All assay figures are in terms of total metals; dry screening on a Hoover laboratory sizer.

As so much depends on the careful running of the flotation plant, special men are picked for this particular work, so as to get the best efficiency and to avoid waste of acid and oil. The workman has to watch carefully the amount of acid used, and he can do this by keeping the solution in Nos. 7 and 8 flotation compartments slightly acid, or almost neutral. He tests this periodically with methyl orange, and can easily detect any change in the quantity of acid required. With regard to the eucalyptus oil, he is guided entirely by the way the float is coming off; the temperature he keeps to 118° F., which is easily regulated, the steam going direct into the No. 1 mixer-box. Probably the most important point of all is the necessity for having a solution not too dense; if the density of the solution exceeds 3,000 grains per gal., the flotation invariably goes off. To avoid this, the workman periodically takes samples of his solution and tests it by hydrometer, and by reference to the following table he can quickly determine the density :

TABLE FOR ESTIMATING SOLUBLE SALTS.

Density at 60° F.	Salts in Grains per Gal.
1026	2000
1028	2200
1030	2350
1032	2530
1034	2700
1036	2900
1038	3050
1040	3230
1042	3400
1044	3600

The solution in circulation should not contain more than 3,000 grains per gallon.

CORRECTION FOR TEMPERATURE IN GRAINS PER GALLON.

Temp. Fahr.	Add. Grains.	Temp. Fahr.	Add. Grains.	Temp. Fahr.	Add. Grains.	Temp. Fahr.	Add. Grains.
61	3	71	83	81	200	91	323
62	6	72	94	82	212	92	336
63	12	73	105	83	225	93	350
64	18	74	117	84	236	94	364
65	25	75	128	85	248	95	378
66	33	76	140	86	260	96	393
67	42	77	152	87	273	97	408
68	50	78	165	88	285	98	424
69	60	79	177	89	298	99	442
70	70	80	190	90	310	100	460

To keep the density of the solution within the limit, a clear-water pipe is attached to each mixer, and is used not only for this purpose, but also for make-up water. The usual custom is, as soon as the solution becomes too dense, to run off one or more of the slime-residue settling-tanks, and make up the balance with clean water again. This serves the purpose of getting rid of the slime-residue, as well as of improving the solution.

The re-flotation concentrate from the third unit is, for the purpose of draining, run direct to a conveyor or draining belt, 36in. wide, working in an iron trough 38in. wide and 15in. deep. The overflow from the trough, which is always very fine and slimy and has a tendency to float, is run to an elevator 12in. by 8-ply, running 300ft. per min., and returned for thickening to a settler 8ft. diam. and 9ft. deep. A spray of clean water plays on the float material in the settler to break it down ; the thickened product from the spigot at the bottom is delivered to the same conveyor near the delivery end, and the overflow from the settler is run back into circuit.

The re-flotation concentrate coming off the conveyor-belt drops into a launder ; some water from the de-leading section is added to wash it down to an elevator 18in. by 8-ply, running 320ft. per min. It is thus elevated to pass over five revolving screens (clothed with 60 by 61-mesh and 36-gauge, running at 11 r.p.m.), and forms the feed to the de-leading section. The re-flotation concentrate, while being washed down this launder, is calibrated by turning the whole of the flow for a timed period into a large box, where it can settle, and the water can be decanted. This calibrating is done at regular intervals, and forms an *estimated* tonnage prior to de-leading.

The over-size from the revolving screens runs to a revolving distributor, then to 7 of the first row of Wilfleys (running at 310 r.p.m.) for treatment. The under-size runs to a distributor, then to 12 of the second and third rows of Wilfleys (running at 310 r.p.m.), six in each row. These tables make a lead and a zinc concentrate, a middling, and slime. The zinc and the lead concentrates each run to their respective elevators, and are delivered into separate tanks for settling and draining. The middling from the first row of Wilfleys is returned by means of an elevator (16in. by 8-ply, 280ft. per min.) to three Wilfleys on the same row, and re-treated, making a zinc and a lead concentrate and a small portion of middling, which is returned. From the second and third row of Wilfley tables come a zinc and a lead concentrate, also a middling and slime.

The middling from the second and third rows of Wilfleys is returned by two elevators (16in. by 8-ply, 280ft. per min.) to eight of the tables in the second and third row, four in each row, and re-treated for a zinc and a lead concentrate, a small portion of middling being made, which is returned.

The slime from the three rows of Wilfleys is run to two 9 by 18in. 3-throw plunger-pumps, running at 32 r.p.m., and pumped to six Callow settlers; the thickened product is run to 12 Weir-Meredith vanners, which make a lead and a zinc concentrate, a middling, and slime. The middling is returned to two Callow settlers, then to five vanners again, and the slime made on all the vanners is pumped to the dam on the flat for future sale or treatment. This slime, although high enough in zinc to go with the zinc concentrate, is so difficult to drain that it was found advisable to store it rather than include it with the coarser concentrate. If it was included with the zinc concentrate, the moisture in the shipping concentrate would be excessive, involving a penalty on all excess moisture over 6%. This zinc slime, which is high in silver and lead (see analysis of zinc slime), is a saleable product by itself, and some has already been sold.

The following table gives an analysis of fine zinc concentrate for three months ended December 31, 1911:

	%
Zinc	35.3
Lead	12.3
Iron	6.8
Manganese	1.5
Sulphur	23.9
Insoluble	13.1
Lime	1.5
Carbon dioxide	2.3
Silver	21.5 oz. per ton

CLASSIFICATION TEST.

Mesh.	Aperture.	Percentage Weight.
On 40	On 0.5	–
,, 100	,, 0.16	4
,, 150	,, 0.09	1
,, 200	,, 0.06	2
Thro' 200	0.06 to 0	93

The overflow water from both the zinc and lead concentrate settling-tanks runs to five Callow settlers; the thickened product from these runs to the slime-pumps, and is re-treated on the vanners. The overflow runs to two large settling-tanks, 60ft. in diam. and 4ft. deep, having an annular overflow. These tanks are built of concrete, and have sufficient area thoroughly to clarify the slime-water. The clarified overflow water runs to two 3-throw 9 by 18in. plunger-pumps, and is pumped to the de-leading section supply-tanks, of which there are two, having a capacity of 10,000 gal. each; it is from these tanks that the wash-water for the screens, Wilfley tables, and vanners is supplied. The residue-sand coming from the No. 8 compartment of the flotation section runs direct to two Callow settlers, 8 by 9ft., having an annular overflow, the material passing over going to the elevator carrying the feed to the mixer, while the thickened product is drawn from the bottom, and runs to a 36in. conveyor draining-belt working in an iron trough; the overflow from the iron trough is pumped by means of a 4in. Robinson centrifugal pump to four round tanks, and the residue-slime allowed to settle. These residue-slime tanks (18ft. diam. and 4ft. 6in. deep) are fitted with annular launders, the overflow going to two 9 by 18in. three-throw plunger pumps, which pump the water into the three supply-tanks (16 by 8ft., 10,000 gal.), each elevated sufficiently high to supply the whole plant by gravitation. The residue-slime from these tanks is pumped out by means of a 6 by 12in. three-throw plunger-pump on to the flat, and forms a dam and bank around the main residue-dump.

The sand-residue is conveyed by two 36in. conveyors running slowly, 18ft. per min., to allow sufficient draining, and is dropped upon an 18in. by 5-ply conveyor-belt (rubber), travelling 210ft. per min., and conveyed for a considerable distance to a boom-stacker, which is building the sand dump to a great height.

Owing to the sloppy nature of the residue and the difficulty experienced in conveying it, also to the essential oil being a solvent of rubber, which quickly causes the belts to deteriorate, it has been decided to install a combination sluicing and conveying plant. By this scheme the residue will run direct to large draining-tanks, as far as the natural fall of the ground will allow, and then the residue, which will by this time have its moisture reduced to about 8%, will be conveyed the rest of the distance. By this scheme the conveying will be reduced by more than half, and there should be less loss by evaporation, thereby effecting a saving in both belting and water.

The following is an analysis of lead concentrate, for three months ended December 31, 1911:

	%
Zinc	15.7
Lead	55.2
Iron	3.4
Manganese	0.6
Sulphur	19.0
Insoluble	2.8
Silver	35.7 oz. per ton

CLASSIFICATION TEST.

Mesh.	Aperture.	Percentage Weight.
On 40	On 0.5	–
,, 100	,, 0.16	22
,, 150	,, 0.09	11
,, 200	,, 0.06	8
Thro' 200	0.06 to 0	59

The following table gives an analysis of zinc concentrate, for three months ended December 31, 1911:

	%
Zinc	45.3
Lead	8.1
Iron	8.3
Manganese	1.6
Sulphur	29.5
Insoluble	4.3
Silver	14.8 oz. per ton

CLASSIFICATION TEST.

Mesh.	Aperture.	Percentage Weight.
On 40	On 0.5	1
,, 100	,, 0.16	32
,, 150	,, 0.09	11
,, 200	,, 0.06	8
Thro' 200	0.06 to 0	48

The finished lead and zinc concentrates (see analysis) from the de-leading section, after leaving the Wilfleys, are elevated into draining-tanks (eighteen for the zinc concentrate and three for the lead concentrate). These tanks, which are fitted with filter bottoms by means of battens, cocoanut matting, and hessian or burlap, are emptied through a circular discharge at the bottom on to a conveyor (one conveyor to each three vats), which conveys the concentrate to another conveyor running at right angles to it, and is discharged into the shipping bins.

The capacity of each zinc-tank is 85 tons, of each lead-tank 125 tons, and the total capacity of the zinc and shipping bins 3,200 tons, making a total holding capacity of finished zinc concentrate 4,730 tons and of lead concentrate 575 tons. The shipping bins are built of stone, fitted with doors and chutes on both sides of the line for filling the shipping trucks; the extreme south end of the bin is partitioned off for the lead concentrate, and the same conveyor is used for conveying the zinc and lead concentrates alternately. After being filled into the Silverton Tramway trucks and sampled, the Zinc Corporation operations are finished.

The results of the operation of the Minerals Separation process in combination with Wilfley tables in this plant are as follows:

	TONS TREATED				ZINC CONCENTRATE				LEAD CONCENTRATE			
		Zn %	Pb %	Ag Oz	TONS	Zn %	Pb %	Ag Oz	TONS	Zn %	Pb %	Ag Oz
1911	211,675	18.56	5.38	8.51	68,452	46.28	7.0	14.3	6,197	16.91	57.2	39.25
1912	345,425	14.4	5.5	6.9	85,354	47.2	7.3	12.5	10,881	14.8	57.9	32.2
1913	350,120	14.1	5.7	5.9	85,377	47.1	7.6	10.4	14,307	15.3	55.4	31.9

The Minerals Separation plants and their capacity now in use are as follows:—Sulphide Corporation, 700 tons; Zinc Corporation, 1,000; Kyloe Copper Mines, 60; Junction North, 600; Silver Peak, 80; Wallaroo and Moonta, 400; Etheridge, 80; Great Fitzroy, 250; Pinnacles, 160; Great Cobar, 400; Chillagoe, 200; Braden, 1200; Cuba Copper Co., 150; Saxberget, 150.

CHAPTER X.

OTHER FLOTATION PROCESSES.

MACQUISTEN PROCESS.

One of the most important of the flotation processes is that invented by A. P. S. Macquisten, which has been installed at the Golconda, Nevada. The apparatus is a tube, so designed as to bring the sulphide particles in the ore on to the surface of the water in a manner best calculated to insure their flotation through the force of surface tension and the inherent quality of the sulphides to resist wetting.

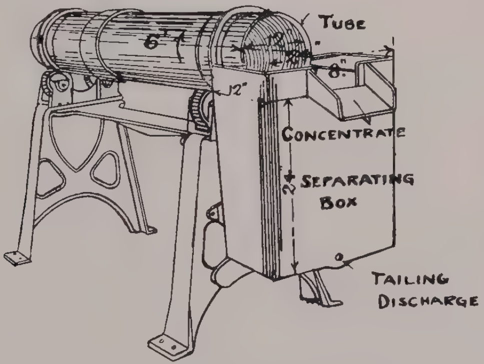


FIG. 51.—Macquisten Tube.

The tube, Fig. 51, is made of cast iron, 6ft. long and 1ft. in internal diameter.* Two tyres, cast on the outside, run upon rollers, upon which the tube rests. The discharge end of the tube is open, while the feed end is closed, except for a hole in the centre to admit the feed-pipe. On the interior of the tube is cast a helical groove of 1½in. pitch. The discharge end of the tube, at the right of Fig. 51, connects with a vessel called the 'separating box', the joint between the box and the tube being watertight, although the tube is free to revolve. The box has an opening for the overflow of water, the lip of this opening being of such a height that about 3in. of water stands in the tube. The feed of pulp to the tube and the discharge of tailing at the bottom of the box are so regulated that the water passing over the lip of the box is about 1-32 in. deep. The floating concentrate passes over this lip into a launder, and the tailing passes out of the hole at the bottom of the box, going to a second tube for further treatment, if necessary, or to the tailing-flume. In operation the tube is rotated 30 r.p.m. in the direction of the helix. The pulp is thus screwed through the tube, and in its advance at every revolution the sulphides are given an opportunity to slide upon the surface of the water and float. As the tube revolves, the pulp is carried up to the surface, and gently rolls over. The angle of emergence is such that some particles of sulphide are at once drained of the adhering water, take on air-films, and float. The gangue simply slides back into the water. This action is taking place at every corrugation, whereby the sulphide particles, which are capable of being held up by the force of surface tension, are given many chances to slide out upon the surface of the water at just the angle at which there is the least likelihood of penetrating the surface.

**Engineering & Mining Journal*, October 26, 1907, 'Concentration Upside Down', by W. R. Ingalls.

In any given tube revolving clock-wise (looking toward the feed end) the flotation takes place chiefly at the left-hand side, where the pulp emerges from the water. The bulk of the pulp in any corrugation either slides back into the water, or floats off; however, a certain amount always adheres to the tube, and is carried over to the water on the right-hand side, where upon meeting the water a further flotation takes place, but naturally this is less than on the left-hand side. Consequently, from the time the pulp enters the first tube there are floating sulphides streaming off from the sides of the tube, which by the time the discharge end is reached form a glistening film, covering the entire surface of the water both in the tube and in the separating-box. This is quite different in appearance from the black frothy scum which rises to the surface in the acid-flotation processes. In separating the chalcopyrite and pyrite at Golconda, the surface of the water is covered with the sparkling bronze mineral, the water looking as if it had been sprinkled with the bronze powder that is employed for decorative purposes. In treating a lead ore, there comes off a film of steel-grey galena; in treating a zinc ore from Joplin, Mo., there was a film of mustard-yellow blende. The flotation is persistent. Once it has been effected, the mineral remains on the water until the latter has overflowed into the launder, which delivers it into the collecting-tank, and even in the latter more or less mineral can be observed floating on the surface. One treatment is not generally sufficient, and the gangue-tailing, with the remaining sulphide, is passed through a second, a third, and a fourth tube. By far the largest amount of concentrate is secured from the first tube.

The capacity of a single tube is 5 tons of ore per day, but as the material must be put through several tubes, the actual capacity of a set would be, say, 5 tons. The ore at the Adelaide mine assays from 2.7% to 3.2% copper, and the percentage of sulphides is low. It is important to note that on a heavy sulphide ore like that at Broken Hill, it would probably be necessary to treat the material through a great many tubes, or else cut the capacity down to a very low point. These tubes have an effective flotation surface of 6 sq. ft. per tube; and, therefore, must be limited in capacity as compared with those processes which increase the available surface by froth production.

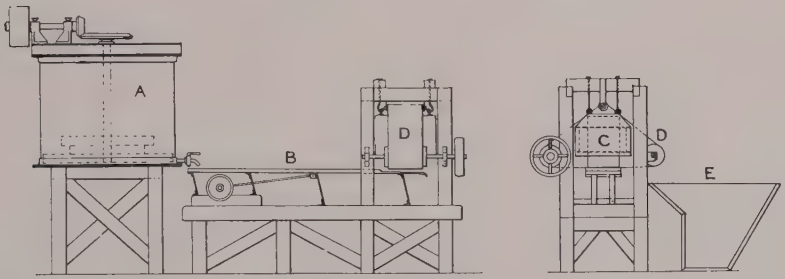


FIG. 52.—Murex Apparatus.

The accounts of this process so far published seem to indicate a lack of facility in the treatment of slime.

MUREX PROCESS.

This process is not strictly of the same class as the others; but as it makes use of the principle of the selective oiling of sulphide particles, and has other similarities to flotation processes, it should be described. In this process the crushed ore is fed to an agitator, Fig. 52. A 'magnetic paint' is fed with the ore in quantity ranging from 40 to 60lb. per ton (4% or 5%) of ore. This magnetic paint is made by mixing one part of oil or thin tar of almost any kind with three or four parts of magnetic oxide of iron, natural or artificial. The oxide must be ground to an impalpable powder. In the mixer A the ore, with the paint and enough water to make a thick pulp, is agitated from five to twenty minutes to mix the substances thoroughly. The paint preferentially adheres to the sulphides because of its oily constituent. When this is accomplished the pulp is fed with some additional water to the upper end of the shaking conveyor B, along which it travels to the magnet C. Around the magnet C is an endless belt D, this belt being between the magnet and the conveyor. As the pulp passes along the conveyor it comes within the magnetic field, and the sulphide particles, partly due to their inherent magnetic permeability and partly to the magnetic permeability of the adhering magnetic paint, are drawn up against the endless belt D and carried outside the magnetic field, where they are washed into the launder E by a stream of water. It is claimed for this process that a great variety of products can be made by varying the material used for mixing with the magnetic oxide. We are already aware that the seriation of minerals, which exercise a preferential oiling, is of much wider range than the seriation of those which will preferentially float, and it is easily believed that among the thousands of oils and coal and wood tar derivatives there may be one which would preferentially adhere to almost any mineral chosen.

This process is a new departure, and well worth research and development. At first glance the successful treatment of oxidized ores, not now treatable by any other process, would seem to lie in this direction. Whether the process could compete with gravity or flotation-concentration for sulphides at present lacks extended demonstration.

SANDERS PROCESS.

This process, tried at Marion, Ky., is somewhat different from the other flotation processes, inasmuch as no acid is used in the bath, the latter being, on the contrary, basic, consisting in fact of a very dilute solution of aluminium sulphate. Moreover, instead of being performed in deep vats, as in the case of the acid-flotation process (wherein the depth of the vat has been found to be a rather important consideration), the basic flotation process is performed in shallow pans, in which mechanical stirrers are operated. Besides the trials at Marion, some experiments with the Sanders process have been made by the Tennessee Zinc Company at Straight Creek, Tenn. The Kelly mine, near Magdalena, N.M., was equipped with a 100-ton plant.

The apparatus (Fig. 53) consists of a vat, preferably round, with a feed-hopper leading below the normal liquid surface. A solution-inlet pipe is placed either in the vat or in the hopper, depending on the ore to be treated. A vertical shaft in the centre of the vat rotates an agitator, the blades of which are arranged to impart a whirling motion to the solution. This whirling motion is designed to assist in raising the valuable mineral particles to the centre of the vat, and to cause a slight cavitation at the centre of the surface, which causes the particles which have been elevated to pass at once to the overflow pipe. The tailing is discharged through a pipe in the centre of the bottom of the vat. A steam-pipe is used on the bottom of the vat to keep the solution at an even temperature.

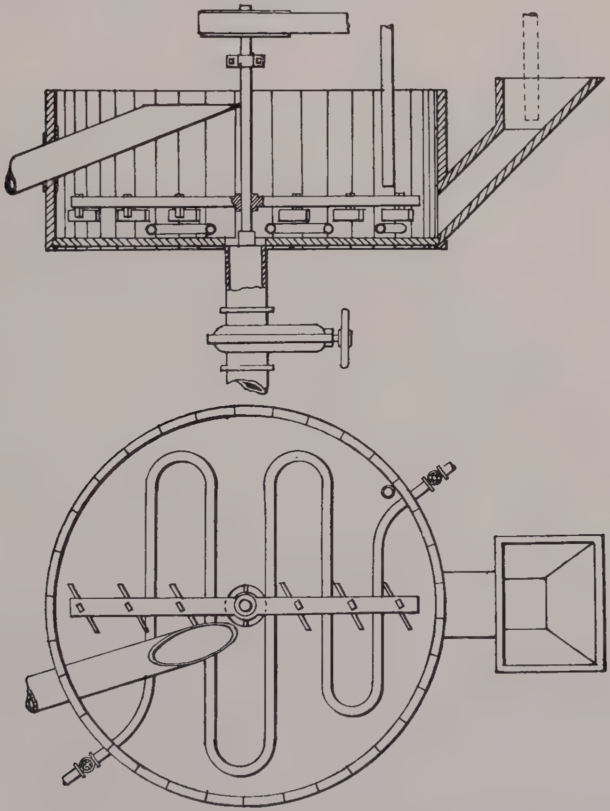


FIG. 53.—Sanders Apparatus.

HORWOOD PROCESS.

The principle of this process is that when a mixture of iron, copper, lead, and zinc sulphides is roasted, the surfaces of the particles of the three former sulphides are changed to oxide and sulphate at a comparatively low temperature, whereas the zinc

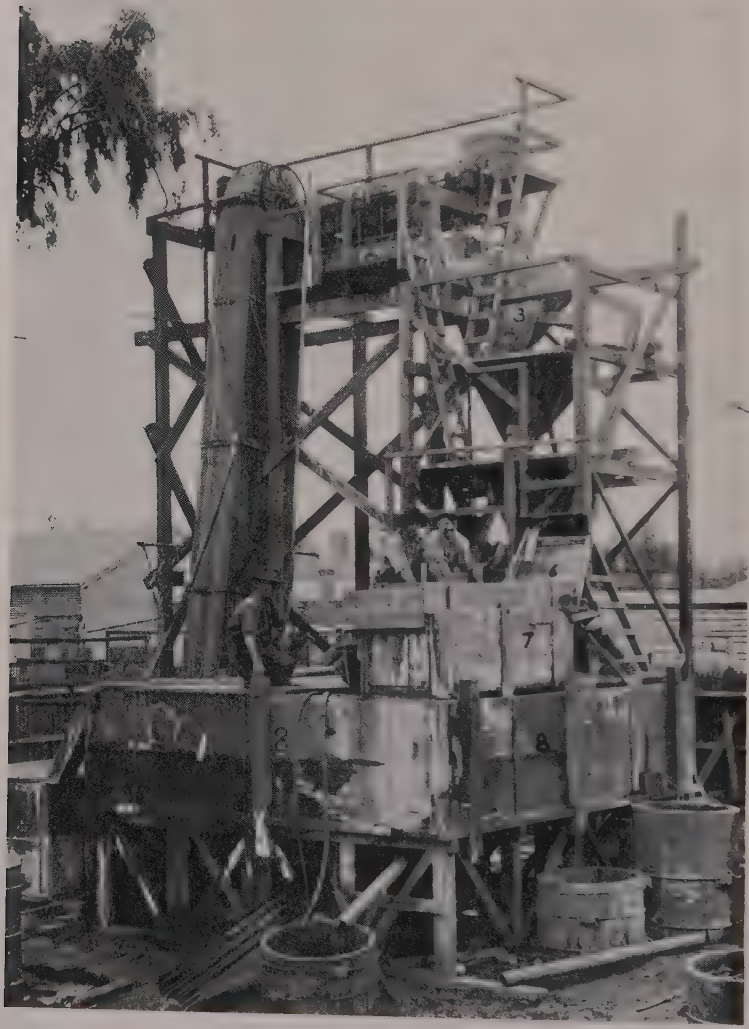


FIG. 54.—Horwood Experimental Plant.

sulphide is practically unaltered. The partly roasted material is then subjected to a heated-acid oil-flotation process, such as the Minerals Separation process, when the zinc sulphides will float away, and the deadened or sulphated compounds of iron and lead will sink with the gangue.*

Preliminary tests must be made on ores which are to be treated by this process, in order to ascertain in just what combination the metals really exist. While the ores at Broken Hill are somewhat granular, the grains of galena and blende being, to a great extent, separable by comparatively coarse crushing, there are many steely-grained admixtures of blende, galena, and pyrite which have to be reduced to a slime before the individual grains are separated.

A photograph of the small Minerals Separation process unit used in extended trials at Bendigo is shown in Fig. 54.

On one lot of Broken Hill slime concentrate the laboratory test showed the concentrate to contain 32.4% zinc and 22.3% lead. This was roasted and treated in the testing laboratory, and two products were made: No. 1, a zinc concentrate, containing 50.8% zinc and 6.3% lead; No. 2, a lead residue, containing 2.6% zinc and 49% lead. About 53½% of the original concentrate was recovered as a zinc concentrate, and about 38% reported as a lead residue. About 85% of the total zinc and 85% of the total lead were recovered in this test.

In actual operation there were obtained from this ore a zinc concentrate, containing 50.4% zinc and 7.3% lead, and a lead residue, containing 12% zinc and 41% lead. The lead residue may be improved by further agitation, raising the content of the lead and reducing that of the zinc.

A complex sulphide from Tasmania, containing an intimate mixture of blende, galena, and pyrite, was also tested. This ore had to be crushed dry to a slime product to insure separation of the blende and galena. The ore assayed 30.9% zinc and 9.9% lead, and yielded in actual operation in the experimental plant a zinc concentrate containing 57% zinc and 5% lead, and a lead residue containing 5.8% zinc and 20% lead. These Tasmanian ores were so intermixed that some mineralogists considered the zinc-lead sulphide to be an isomorphous compound.

***Engineering & Mining Journal*, February 26, 1910, p. 460, 'Horwood Process', by Donald Clark.

Preliminary laboratory tests must be made on ores to be treated by this method, to determine the percentage of flotation obtainable, the amount of lead required to be converted to sulphate, acid consumption, crushing, etc.

The ore is roasted in an Edwards furnace, the temperature being kept below the ignition point of zinc sulphide ; usually the temperature of the heated gases passing over the ore, as tested by a pyrometer, varies between 300° and 400° C. The end point of roasting is determined by prior laboratory experiment, and varies with the composition and fineness of the ore. Tests are made from time to time on the furnace product to find the amount of lead present as sulphate, and as soon as the predetermined amount is reached the ore is discharged from the furnace.

In the first test the ore was roasted in charges until sufficiently sulphated ; but latterly, and with more satisfactory results, a continuous feed and discharge and a slow rabble-motion were used. The first to oxidize is the pyrite, and next the galena, the zinc sulphide being almost unaffected. The time required for Broken Hill slime - concentrate, when roasted in charges, was about three hours.

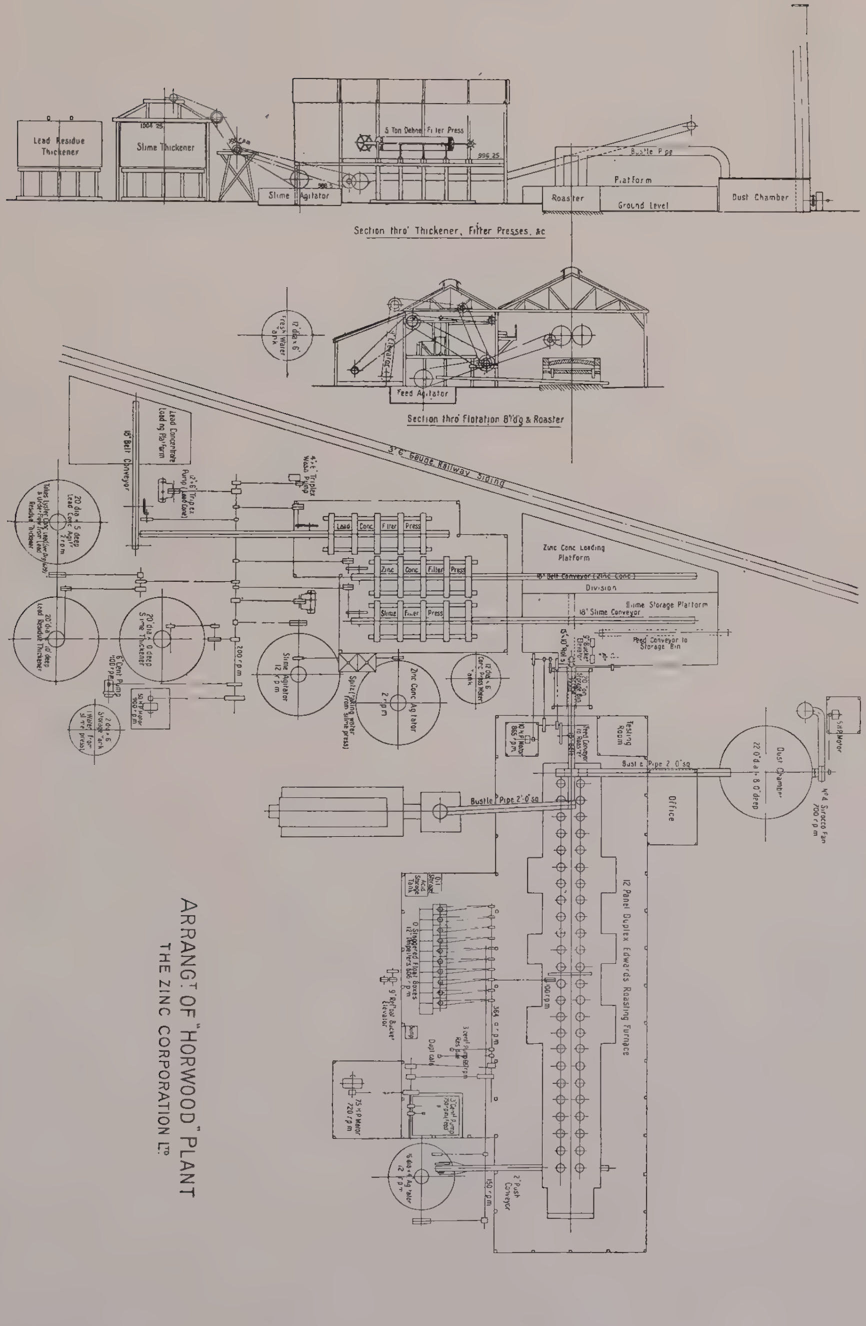
The partly roasted ore is fed into the boot of a bucket elevator with about five times its weight of a dilute solution of sulphuric acid, heated to near the boiling point. The amount of acid required is determined by laboratory experiment, and is as high as 100lb. per ton treated.

The zinc, being unaltered by the slight roast, floats at the surface as mineral froth in the same way as was described in Chap. IX., while the iron and lead particles, being altered on the surface to soluble sulphates, are wetted by the water and sink. It may be noted here that the extreme limit of water-wetting is the case of solubility.

Kenneth A. Mickle* proposes to get an analogous alteration of the galena particles by treating the crushed material with ferric chloride, and then subsequently treating by a flotation process.

The installation of the Horwood process at the Zinc Corporation gave the following results :

**Australian Mining Standard*, May 2, 1912, p. 404.


Lead Residue Thickener
Slime Thickener
Slime Agitator
5 Ton Dehne Filter Press
Bustle Pipe
Platform
Roaster
Ground Level
Dust Chamber
Section thro' Thickener, Filter Presses, &c
12' dia. × 6' Fresh Water Tank
Feed Agitator
Elevator
Section thro' Flotation B'ld'g & Roaster
3' 6" Gauge Railway Siding
Lead Concentrate Loading Platform
18" Belt Conveyor
20' dia. × 5' deep Lead Conc. Agitator 2 r.p.m.
4" × 6" Triplex Wash Pump
Lead Conc. Filter Press
Zinc Conc. Filter Press
Slime Filter Press
Zinc Conc. Loading Platform
18" Belt Conveyor (Zinc Conc.)
Division
Slime Storage Platform
18" Slime Conveyor
Feed Conveyor to Storage Bin
20' dia. × 10' deep Lead Residue Thickener
20' dia. × 10' deep Slime Thickener
200 r.p.m.
Slime Agitator 12 r.p.m.
Zinc Conc. Agitator 2 r.p.m.
12' dia. × 6' Conc. Press Water Tank
6" Cent. Pump
50 H.P. Motor 960 r.p.m.
20' dia. × 6' Storage Tank (Water for slime press)
Testing Room
Bustle Pipe 2' 0" sq.
Dust Chamber 22' 0" dia. × 8' 0" deep
No. 4 Sirocco Fan 700 r.p.m.
Office
12 Panel Duplex Edwards Roasting Furnace
Oil Storage
Acid Storage Tank
10 Staggered Float Boxes 12" Impellers 500 r.p.m.
9" Ref. Bucket Elevator
364 r.p.m.
Duplicate
75 H.P. Motor 720 r.p.m.
16' dia. × 6' Agitator 12 r.p.m.
150 r.p.m.
2" Push Conveyor
100 r.p.m.

ARRANGT. OF "HORWOOD" PLANT
THE ZINC CORPORATION LTD.

SELECTIVE FLOTATION RESULTS (HORWOOD PROCESS) WEEK BY WEEK.

WEEKS ENDING 1913.

		July					August				September				October					November				December					Total
		2	9	16	23	30	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	3	10	17	24	31	
Feed to Roaster	Tons	Plant idle owing	to	Alterations	Tonnage treated too small to extract figures (started running on 21st inst)			114	259	266	328	259	300	289	177	Plant only ran 16 hours owing to shortage of water, etc.	258	307	316	329	336	373	304	264	243	322	304	117	5465
	Zn %							37.6	38.0	34.9	37.4	38.3	38.1	38.3	39.2		38.5	37.3	38.3	37.3	38.2	38.2	38.0	38.2	38.4	40.0	40.7	40.8	38.2
	Ag. ozs.							23.3	24.1	23.7	25.5	26.4	25.8	25.4	24.5		25.1	25.7	24.7	25.2	23.4	24.0	23.2	20.3	17.8	20.1	19.7	20.2	23.4
	Pb. %							17.3	17.0	17.0	16.9	16.9	16.7	16.6	16.6		17.6	17.5	17.3	16.9	16.7	16.8	16.6	16.3	16.1	15.2	15.0	14.1	16.5
Concentrate loaded	Tons							73	164	176	178	165	169	199	121		146	187	203	211	222	252	218	188	168	231	217	91	3579
	Zn. %							44.5	45.3	45.5	47.8	47.7	48.1	46.4	46.9		48.2	47.5	48.0	46.9	47.5	47.9	46.6	46.0	46.6	46.0	47.1	46.6	46.8
	Ag. ozs.							17.2	18.0	18.8	16.1	18.5	17.3	18.8	18.4		17.5	17.6	17.4	17.6	17.2	16.5	17.3	13.0	12.5	14.7	14.2	15.7	16.7
	Pb. %							12.2	11.3	11.5	9.0	10.0	9.1	10.9	10.7		10.1	9.3	9.7	10.3	9.4	9.9	9.9	8.4	9.0	9.4	7.0	7.8	9.6
Residue to dam	Tons							36	81	91	121	86	108	67	50		107	113	105	91	101	100	69	71	67	76	72	26	1636
	Zn. %							21.3	23.8	17.0	20.4	21.6	21.5	14.1	17.4		22.3	17.5	16.1	14.5	15.0	13.7	12.2	13.2	18.3	14.0	12.1	26.1	17.6
	Ag. ozs.							33.6	36.0	38.3	43.2	42.9	42.7	45.7	44.6		37.9	41.4	43.3	41.6	40.0	41.6	41.8	37.1	33.7	39.7	42.9	32.0	38.6
	Pb. %							30.3	28.3	29.8	30.9	30.8	30.7	34.5	33.9		30.4	34.0	35.7	34.1	34.9	36.2	37.3	39.1	38.2	39.4	39.6	28.0	33.8
Loss by difference	Zn,							6.3	5.1	+3.9	10.2	2.1	8.5	8.1	5.7		4.6	5.0	5.8	8.8	6.0	5.6	5.8	5.1	3.1	9.3	9.3		5.8
	Ag.							7.0	6.0	+7.7	3.2	1.4	2.8	7.1	+2.5		+1.9	+1.0	2.6	9.6	0.4	7.0	5.9	5.4	0.8	1.0	+2.6		2.3
	Pb.							+0.3	5.7	+5.2	3.6	1.4	2.8	6.0	+2.1		+3.9	+4.1	3.5	4.6	0.3	2.0	4.3	0.3	0.1	+5.5	+1.6		.6
	Tons							5	14	+1	29	8	23	23	6		5	7	10	27	13	21	17	5	8	15	15		250

HYDE PROCESS.

James M. Hyde, of Basin, Montana, has developed a flotation process for treating the ores of the Butte & Superior Company. The experiments at Basin were so successful that the Butte & Superior Company has erected a mill at Butte on lines laid down by Mr. Hyde.

The description of the process is given in U.S. Patent No. 1,022,085, as follows: The ore, after crushing, is mixed with acid before thickening in a tank A (Fig. 55). It has been found that adding the acid in advance cuts down the amount required, and promotes the settlement of colloidal material, which may be further aided, if necessary, by adding copperas, alum, or some other coagulant. From the thickener A the pulp is pumped to the first treatment tank B, where oil is added and the entire mass agitated. A float concentrate is then taken off, and the gangue goes to the tank B′, where the process is repeated, and thence to B″, where the pulp is agitated and a third concentrate taken off. From B″ the gangue is discharged as a final tailing.

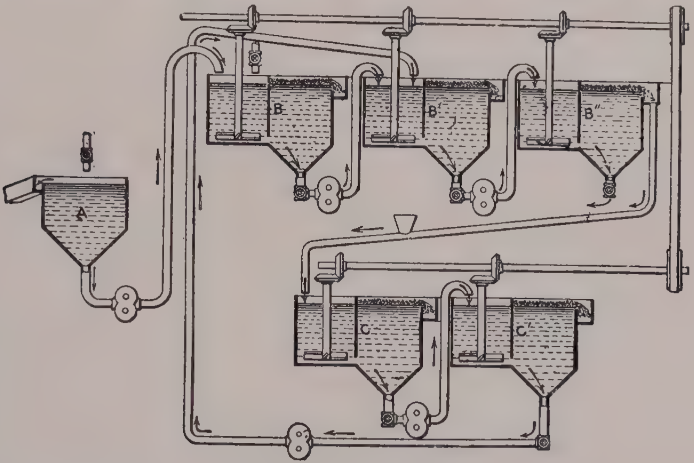


Fig. 55.—Hyde Apparatus.

There is considerable silica mixed with the first concentrate, so it is re-cleaned in a second device CC′, the concentrate from which is the final product, while the tailing is all sent back to B′.

As an example of actual work with this machine, the following description is given: The material treated was the slimy portion of an ore, consisting principally of quartz, blende, and various amounts of decomposed granite, in which the felspars were largely kaolinized. About 92% of this material was fine enough to pass a 150-mesh screen. Without the use of a coagulant, part of the slime, containing a notable percentage of zinc, would remain in suspension over 24 hours.

The pulp, as produced, contained from 29 to 100 or more parts of water by weight to one part of ore, to which was added, before thickening, from a quarter to a half a pound of sulphuric acid per ton of ore. The thickened pulp was heated in the flotation machine by live steam to expand the gas bubbles, and facilitate coating the sulphide particles with the oil used, which, in this case, was 'candle-maker's red oil'. The oil consumption cannot be calculated beforehand, but must be gauged by experience. The ore fed carried 23.3% of zinc, the concentrate 51.4%, and the tailing 3.2%, indicating a 91% recovery. The concentrate from the primary section of the machine ran 38% to 42% of zinc.

The Butte & Superior ore contains rhodochrosite, quartz, and sulphides, and is an ideal ore for flotation. The ore has been treated for some time at the Basin reduction plant, rented from the United Copper Company by the Butte & Superior Co. The mill was too small and the rental heavy, so plans were drawn for a 1,000-ton mill, one 500-ton unit of which was in operation by the end of May, the other about a month later. The installation consists of a crushing plant, jigs, hydraulic classifiers, a slime-plant for oil-flotation, and Wilfley tables, which are used only to separate the lead from the zinc. The ore is first reduced by rolls to 6-mesh, and, after jigging, the tailing is re-ground to 40-mesh, and the tailing from the fine jigs ground to 100-mesh, and treated by oil-flotation. The pulp is thickened to three parts water and one part ore, and is mixed with a small quantity of oil and sulphuric acid and agitated.

The following are the results of the operation :

EFFECT OF FINENESS OF FEED ON RECOVERY.

500 GM. TESTS.

	Feed.	Conct.	Tail.	%
	Assays	per cent.	Zinc.	Recovery
Crude Ore through 60-mesh ..	18.8	51.1	—	83.0
	18.8	45.7	—	87.0
	22.6	47.2	2.4	92.7
	22.6	48.5	2.7	90.1
Crude Ore through 150-mesh ..	22.1	47.9	0.7	97.2
	22.1	52.8(a)	1.1	93.5
		Mids.	4.8	
Jig Tailing through 60-mesh ..	10.9	39.5	2.7	73.2
	10.9	42.0	2.8	75.5
Jig Tailing through 150-mesh ...	10.4	40.1	1.4	87.6
	10.4	48.9(a)	1.7	79.4
		Mids.	4.7	

(a) These concentrates are the only ones in the above series which received any cleaning re-treatment. The material marked ‘ Mids ’ is the tailing resulting from this re-treatment. In actual milling, where the middling is returned to the rougher for re-treatment, it is found that the tailing is practically as low when the cleaner is used as when it is not, and the cleaned product runs 5% to 8% higher than the uncleaned.

SUMMARY OF FLOTATION TESTS.

	No.	Gal. treated per min.	Ratio water to ore.	Rate of Tons per day Ore.	Rate of Tons per day Conc.	Assay. Feed.	Assay. Conc.	Assay. Tail.	Recovery. %
Complete Hyde Machine Regular Mill Feed	11	166.9	6.9-1	142.3	71.3	25.8	50.1	2.7	94.6
Rougher Hyde Machine Built up Feed	12	156.1	3.09-1	281.7	131.4	20.1	41.8	1.1	97.0
Rougher Hyde Machine Built up Feed	13	196.3 166.8	2.1	516.76 439.0	190.3 190.3	21.8	43.2	5.5	85.7

SCREEN-ANALYSIS OF MILL PRODUCTS.

BUTTE AND SUPERIOR ORE.

Mill Feed 21.1% Zinc. 500 gm. Sample, 4 days sample assay.

Crushed through 5 mm.

		Weight.	% Weight.	Assay % Zinc.
On	20	332.2	66.44	18.3
	40	56.7	11.34	19.4
	60	24.2	4.84	22.5
	80	11.5	2.30	23.5
	100	9.9	1.98	24.7
Through	100	61.9	12.36	24.9
		496.3		

COARSE MILL TAILING.

Sample for 2 days, 500 gm. Sample, 9.4% Zinc.

On	20	136.3	27.26	8.6
	40	183.8	36.76	9.7
	60	67.6	13.6	9.7
	80	34.6	6.92	8.9
	100	17.6	3.52	11.1
		497.4		

TABLE TAILING.

		Weight.	% Weight.	Assay % Zinc.
On	40	42.6	21.3	6.1
	60	29.1	14.5	4.9
	80	22.7	11.3	5.9
	100	24.5	12.2	5.1
	150	13.0	6.5	5.0
Through	150	64.2	32.1	11.3

SCREEN-ANALYSIS FLOTATION CONCENTRATE AND TAILING.

Concentrate No. 56 from ore assaying 22.6% Zinc. 100 gm. Sample.

Whole Sample, 47.2% Zinc.

		% Gms.	Fe.	SiO_2	Zinc.
On	80	16.0	3.2	24.8	43.6
	100	18.0	3.4	22.0	46.0
	150	14.0	3.6	20.2	46.4
Through	150	52.0	3.4	17.9	47.8

Concentrate No. 58, Ore as above.

Whole Sample, 48.5% Zinc.

		% Wt.	Fe.	SiO_2	Zinc.
On	80	13.5	3.1	21.7	46.6
	100	22.4	3.1	18.2	48.5
	150	9.8	3.2	16.4	49.5
Through	150	54.3	3.3	14.3	50.0

2.0% Zn Tailing No. 65 from Fine Jig Tailing 6.1% Zinc.

		% Wt.	Assay % Zinc.
On	80	26.7	3.9
	100	45.8	3.0
	150	16.5	2.6
Through	150	11.0	1.8

2.7% Tailing No. 59. From Mill Feed, 22.6% Zinc.

		% Wt.	Assay % Zinc.
On	80	20.8	4.0
	100	18.0	3.4
	150	14.5	2.7
Through	150	46.7	2.0

2.8% Zn Tailing No. 63. From Coarse Jig Tailing, 10.9% Zn

		% Wt.	Assay of Zinc.
On	80	23.4	4.0
	100	17.8	3.4
	150	9.7	3.0
Through	150	49.1	2.0

WOOD PROCESS.

In Bulletin No. 71 of the American Institute of Mining Engineers, November, 1912, p. 1,227, Henry E. Wood describes his flotation process. This is the first appearance of this branch of metallurgy in the transactions of that honourable Society. He says his earliest work with flotation was done in 1895, when he used various oils, grease, soap, &c., with results that were remarkable. He did not realize then that with water alone equally good separations could be made. Up to 1906 his endeavours were confined to attempts to keep the concentrates on the tables well wetted and away from exposure to the air. In common with others, he observed that when there was any obstruction in the wash-water on the table of sufficient size to divert the water to either side the concentrates collected, and on exposure to the air would promptly float away. This convinced him that the sulphides were all good "swimmers," and that if, instead of endeavouring to drown them they were given a chance, they would all float.

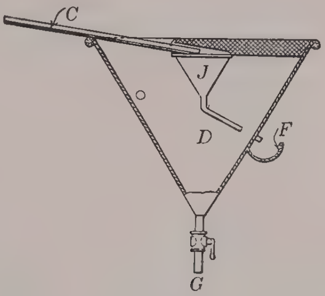


FIG. Z.

Having successfully demonstrated this fact, as well as another equally important—namely, that practically all the oxides are quickly wetted, become saturated like a sponge, and, sinking under the surface-film, become subject to gravity conditions—he commenced his experiments.

He found that if dry-crushed ore, not necessarily very fine, was gently deposited upon a swiftly-moving sheet of water, separation of the sulphides from the gangue took place. Retarding the current permitted the gangue to sink, while a film of sulphides remained on the surface. To collect this film he has devised three types of machine. These are all about the same type, his B (Fig. *Z*) machine having a startling similarity to that ancient one of Bradford, illustrated in Chapter XI. His machines (types A and C) also have strong resemblances to Bradford and De Bavay. The feed of the type B machine is delivered over the inclined plane C to a conical tank D, in which a rapidly-revolving motion with vortical effect is given to the surface of the water by means of a water-jet against the side of the tank. The feed falls upon an inclined sheet of water. The film of sulphides is guided by means of partly-submerged vertical screens E to a funnel J, the outlet of which penetrates the side of the tank, where the concentrates are delivered to a launder E.

Wood gives a large amount of very interesting experimental data in the article above mentioned, to which the reader is referred.

LYSTER PROCESS.

Fleury James Lyster, an employee of the Zinc Corporation, discovered that galena may be separated from blende without any preliminary treatment by subjecting the ore or metalliferous materials to a flotation separation treatment at a low temperature with eucalyptus oil or other frothing agent, and with agitation or aeration in a neutral or alkaline, but not acid, solution of the sulphates, chlorides or nitrates of calcium magnesium, sodium potassium, or mixtures of these substances; also discovered that neutral or alkaline, but not acid, solutions of other suitable sub-

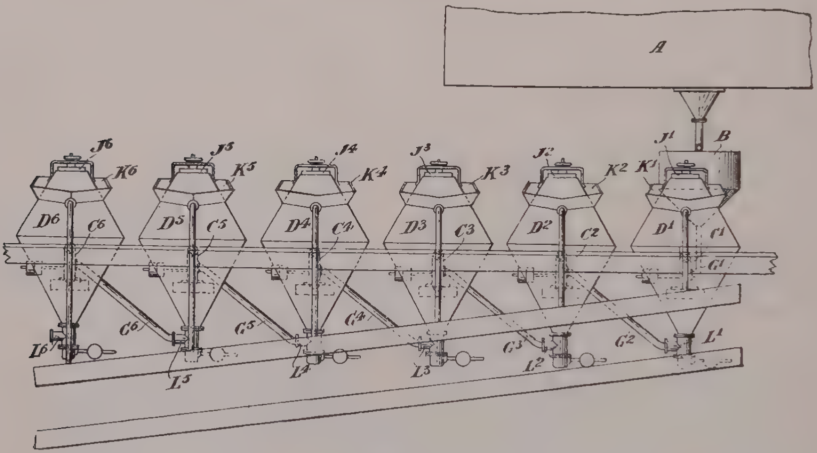
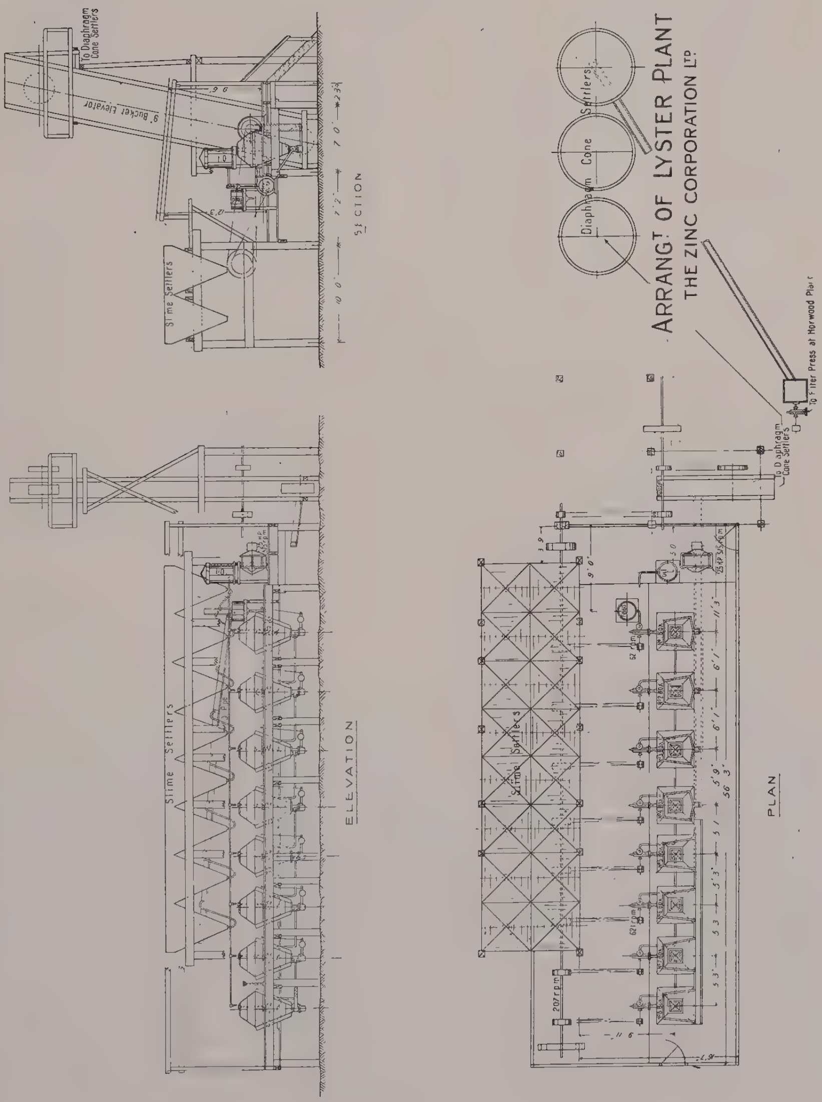


Fig. X.



ARRANGT OF LYSTER PLANT
THE ZINC CORPORATION LTD

stances can be employed, such as sulphate of manganese, zinc, or iron, bi-sulphate of sodium and potassium, chloride of barium, carbonate and bi-carbonate of sodium, and potassium of mixtures of these substances.

He found that mineralised water, such as is obtained from the underground workings at Broken Hill, Australia, is a suitable solution for carrying on his process. Such water gives approximately the following analysis :—

	Grs. per Gall.	
Total soluble solids		666
Volatile and organic matter ..	57.2	
Silica	2.2	
Calcium oxide	78.2	
Magnesium oxide	53	
Sulphur troxide	205	
Chlorine	178	
Manganese	30.3	
Zinc	5	
Alumina	4	
Carbon dioxide	9.3	
	622.2	

—and is alkaline in reaction when submitted to the usual test with methyl orange.

The ore is first ground to a suitable degree of fineness (preferably to slimes so that the different metallic sulphide particles are disassociated from each other). This finely ground ore, with its accompanying circuit water (which is a solution such as hereinbefore described) is led into a settler or thickener A (Figs. X and Y) to remove excess water. The thickened pulp is then led into a vessel B, from which it passes to the first centrifugal pump C1 of series C1, C2, C3, C4, C5, C6. These centrifugal pumps are each connected to the individual members of a corresponding series of separating boxes—D1, D2, D3, D4, D5, D6. These centrifugal pumps act as agitators or mixers, and means are provided (such as an inlet pipe E) for feeding in the requisite amount of eucalyptus oil or other frothing agent, about 2lb. per ton of material, treated as well as the requisite amount of air (such as by tap F) into the suction pipe G1 thereof, which is connected to the feed vessel B.

The centrifugal pump C1 draws in pulp, air, and frothing agent, and produces an intimate mixture, which is discharged through the outlet pipe H to the separator box D1, the delivery of the pump being controlled by the admission of air by the tap F. The particles of lead sulphide (galena) are found to rise to the top of the separator box D1, where an inverted pyramid (J1) diverts the froth towards the discharge lip or launder K^1, from which it flows to the receptacle for settling and collecting the lead concentrate. The particles which do not rise or float together with the balance of the water sink to the bottom of the box D^1, and are there withdrawn by the outlet pipe L^1, which is connected to the suction pipe G^2 of the next pump C^2 of the series, when the operation is repeated, the residues of one separator box D^1 passing to the centrifugal pump C^2 of the next in series.

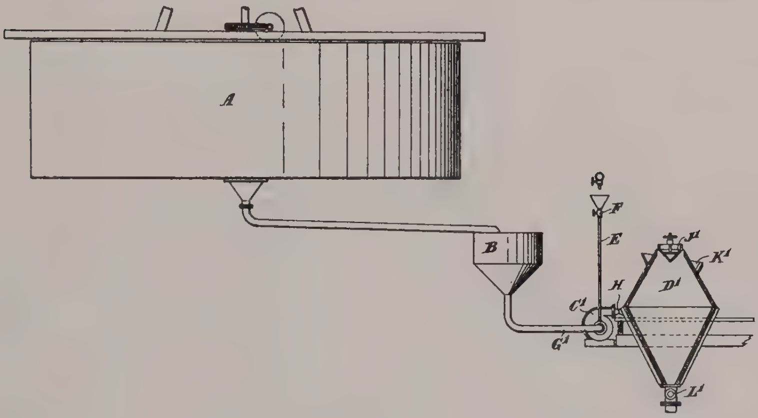


FIG. Y.

SELECTIVE FLOTATION RESULTS (LYSTER PROCESS).

WEEKS ENDING 1913.

A small plant at the Zinc Corporation works gave the following results :

		July					August				September				October					November				December					Total
		2	9	16	23	30	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	3	10	17	24	31	
Feed	Tons	328	333	328	319	333	335	327	298	320	331	306	325	321	264	189	265	330	326	316	321	320	342	252	278	331	265	Mine Closed Down.	8003
	Zn %	9.9	9.0	9.2	9.1	9.5	9.8	9.1	9.1	9.2	8.7	8.8	9.2	8.5	8.8	9.3	9.7	9.7	10.2	9.9	10.9	10.4	11.0	10.9	10.3	10.2	9.9		9.6
	Ag. ozs.	3.1	3.0	2.5	2.6	2.9	2.9	3.0	3.2	3.0	2.7	2.9	2.5	3.2	2.4	2.6	2.9	2.4	2.8	3.1	3.3	3.2	3.0	3.0	3.1	3.1	3.0		2.9
	Pb. %	14.0	13.1	14.7	14.8	13.9	15.1	14.5	15.7	14.8	13.4	13.4	12.6	12.7	12.5	13.7	13.7	12.1	15.0	15.4	16.4	16.2	16.5	16.8	15.2	14.2	14.2		14.4
Concentrate	Tons	72	72	72	72	69	72	72	72	70	63	54	54	54	45	36	49	55.0	66	72	76.0	79	79	61	61	66	57		1670
	Zn. %	9.3	7.9	7.8	7.6	7.4	7.2	7.4	7.3	7.8	6.9	6.5	6.7	7.1	6.7	6.9	6.5	6.4	7.2	7.7	8.1	7.6	6.9	6.6	6.4	6.4	6.4		7.1
	Ag. ozs.	9.8	8.8	9.1	9.0	10.4	10.0	10.2	10.6	10.0	9.7	10.6	11.0	10,2	10.0	10.0	10.2	10.2	10.0	10.7	11.5	10.1	10.4	10.0	10.4	10.6	10.8		10.1
	Pb. %	55.4	52.8	56.8	56.8	57.0	56.4	56.3	57.6	57.2	57.3	58.9	58.2	56.0	57.8	55.0	58.1	54.9	58.1	56.9	57.7	56.0	60.1	58.6	54.3	56.3	54.4		56.7
Residue	Tons	256	261	256	247	264	263	255	226	250	268	252	271	267	219	153	216	275	260	244	245	241	263	191	217	265	208		6333
	Zn. %	10.0	9.3	9.6	9.6	11.4	10.5	9.6	9.7	9.6	9.1	9.3	9.7	8.8	9.3	9.8	10.4	10.4	10.9	10.6	11.7	11.4	12.2	12.3	11.3	11.2	10.4		10.3
	Ag. ozs.	1.3	1.4	0.6	0.8	1.0	1.0	1.0	0.8	1.0	1.0	1.2	0.8	1.8	0.8	0.8	1.2	0.9	1.0	0.9	0.8	1.0	0.8	0.8	1.0	1.2	0.8		.98
	Pb. %	2.3	2.2	2.9	2.5	2.7	3.8	2.7	2.3	2.9	3.1	3.6	3.5	2.8	3.2	3.9	3.6	3.5	4.0	3.2	3.6	3.2	3.4	3.5	4.2	3.7	3.2		3.2
Recovery %	Ag. ozs.	68.5	63.4	81.0	76.6	73.1	73.4	74.2	80.8	73.7	69.5	65.4	73.1		72.0	74.4	65.8	69.4	71.7	78.6	81.7	76.8	79.6	79.8	74.5	69.3	78.7		73.8
	Pb. %	87.1	87.0	84.7	86.7	84.8	80.3	85.4	88.8	84.5	81.4	77.8	76.7		79.0	76.7	78.7	75.7	78.6	84.2	83.4	85.2	84.2	84.4	78.6	79.1	82.4		82.2

THE OWEN PROCESS.

The system of working employed in the Owen process is to violently agitate a mixture of fresh cold water and a small percentage of eucalyptus oil, equal to about 2ozs. per ton, in a cylindrical vessel. The agitator used is shown in Fig. N. After thoroughly emulsifying the liquid with the addition of air through small air pipes in the bottom of the machine (the air inlets are controlled by a rubber tube sleeve) the slime charge is added, together with

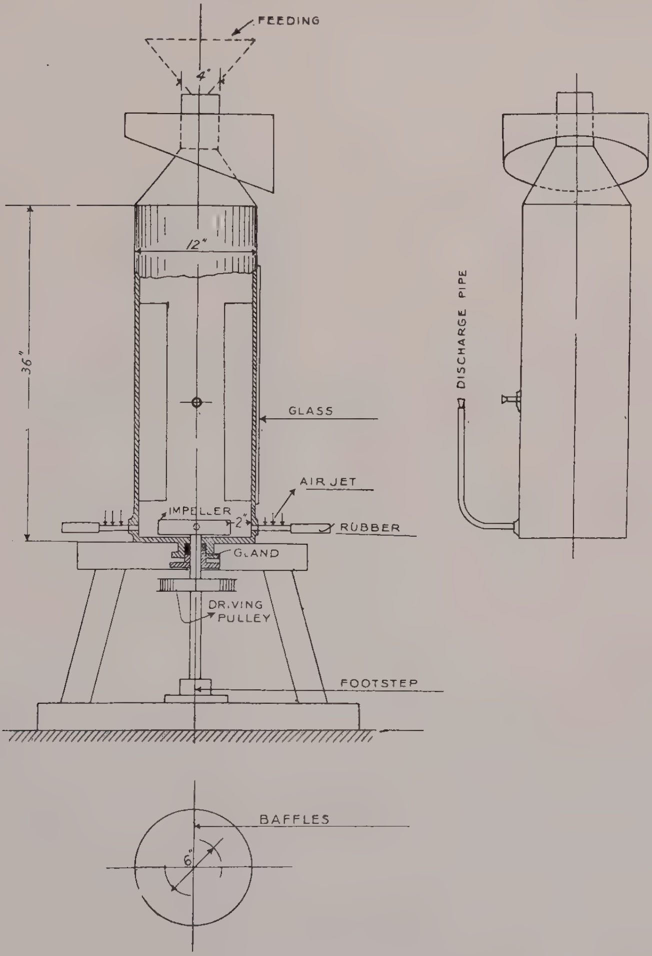


FIG. N.

a continuous stream of fresh water, which raises the float to the top discharging point of the vessel. The first float, which takes about three minutes to effect, is the lead concentrate, which is gradually drawn off until the froth shows a brown appearance, when agitation is immediately stopped. The mass is then allowed to settle, and after a few minutes sulphuric acid, equal to about 20lbs. per ton, is added, together with more oil equal to a few ounces per ton. After this the agitation is resumed, and more water is added continuously, until the float, which now has a very brown appearance, is all driven over the annular discharge launder. The residue is discharged through the bent pipe, shown in the sketch, by turning it down into a bucket.

BRADFORD PROCESS.

This is a process worked out by Leslie Bradford in the flotation plant of the Broken Hill Proprietary Company. By careful study of various solutions, which would preferentially wet certain sulphides, he has evolved a practical way of making zinc sulphide float in the presence of lead sulphide. The ground material is submitted to a flotation separation, which consists of agitation and aeration used with a frothing agent, such as oleic acid with heat. The solution, which he calls a wetting solution, is a solution of sodium chloride acidulated with sulphuric or other commercial acid in most cases, although it is possible on certain types of material to use a wetting medium, which may be neutral or alkaline. The temperature of the operation is 120° to 160° F. The operation can be carried out in any well-known apparatus in the ordinary way, and he found that the preferential flotation was effected, inasmuch as the lead sulphide particles were temporarily wetted, and thereby rendered non-susceptible to flotation, remaining as a residue ; while the zinc sulphide was not wetted, and floated as a froth.

This method—one could hardly call it a process—may work out to be an extremely valuable variation, but it is very difficult for one to see exactly wherein it differs from the old and well-known oleic acid froth process, with the single exception that the operation is carried on in a solution of common salt.

CHAPTER XI.

ECONOMICS.

Though the flotation processes have a restricted range of application, yet the development has been, and is, so rapid that no one can prophesy what the end will be. Up to the present comparatively few minds have been working on the idea, but with the wider human effort which within a few years will be brought to bear, it is quite likely that the applicability will be considerably increased. There is reason to believe, also, that the forces of surface tension and adhesion could be profitably employed in industrial operations other than ore concentration, and especially in operations where coagulation will give rise to new combinations. Buoyancy-flotation has already been applied to the separation of imperfect oranges from perfect ones, and also to the separation of wood fibre from *guyaule* rubber.

LIMITATIONS.—There are, in the present state of our knowledge, four main limitations to the applicability of these methods. The first is that in general they are limited in their usefulness to those ores where certain valuable metals are in the form of sulphides, which need to be separated from worthless gangue. Some flotation patents have claimed to be able to treat ores where the minerals are carbonates or oxides, but these claims are at the present time over-optimistic, and so far there is not any demonstrated method of concentrating carbonates and oxides by flotation. It is the metallic sulphides, as distinguished from the carbonates and oxides, for which the oils and gases used in these processes have a marked selective action. The carbonates and oxides are not without some adhesive quality, but this quality in them is so feeble on the one hand as compared with the sulphides, and so little differentiated from the adhesive quality of the gangue on the other, that it has been impossible so far to found a commercial process on this quality. This is an important point for research and invention, as it it quite likely that if a process was found by which the carbonates and oxides could be separated from gangue by flotation, it would also obviate the second dominant limitation of the process. The most likely line of research at present in sight that would seem as if it might accomplish the desired end, is along the line of soluble frothing agents, and especially the multitude of little known products from the destructive distillation of various woods; a method which aims at coagulation of the mineral by means of slow agitation may also be beneficial.

The second limitation to the usefulness of the processes is that, in general, they are not applicable to ores which contain more than 5% of those carbonates which are soluble in dilute acid. For the acid-flotation processes a small proportion of calcium carbonate is necessary, in order that the acid may have something from which to generate carbon dioxide gas. Those processes which use air as the flotation gas do not need any carbonate present; it is a detrimental element in this case because it unnecessarily consumes acid. Four to five per cent. of calcium carbonate is the maximum required for acid-flotation processes; more than this unnecessarily consumes acid. The ideal ore for the acid-flotation processes is the Broken Hill tailing from the table concentrators, having the following analysis:

	%
Pb	7
Zn	20
Fe	8
Mn	3
S	14
CO_2	3
SiO_2	42
CaO	1
O, etc.	2

An ideal ore for oil-air flotation methods is that of the Guernica mine in Bolivia, which has the following analysis:

	%
Cu	3
Fe	12
S	10
Al_2O_3	2
SiO_2	72
O, etc.	1

This latter ore would require the addition of calcite in order to get any result with the acid-flotation processes.

Some ores which have up to 10% CO_2 can be successfully treated by the oil-air flotation processes by adding a small amount of acid at the proper moment of flotation; whereas an attempt to treat these ores by mixing them with a comparatively strong acid solution, such as is used in the acid-flotation processes, results in the consumption of all the acid in the circuit without getting the desired result. Some recent patents claim useful results without acid, and the present practice at the Great Fitzroy mine in Queensland is of this order.

Ores like that of the San Francisco del Oro mine and the Avino mine in Mexico have proved difficult to treat, because these deposits occur in a calcareous country-rock, some of which is necessarily mixed with the ore. The former also contains fluorite, and this fluorite shows a decided tendency to float, thus contaminating the zinc concentrate with an element which the zinc buyers penalize most stringently. In this point, then, we have the third limitation to these methods—that is, they are limited to those ores which do not contain floatable minerals that are deleterious to the concentrate. Besides the fluorite ore mentioned above, the mixed sulphide ores of Scandinavia fall into this class, because they contain such a large percentage of iron pyrite, which floats, that the tenor of the concentrate is thereby reduced to a point so low that the product is unmarketable. The market demand for concentrate also bears on the cases of graphite and molybdenite. There has been a great deal of unjustified optimism concerning the supposed revolution which flotation processes would bring about in the treatment of these two substances. In the case of graphite, the fine crushing tends to destroy one of the best qualities of the graphite, because the best prices are paid for the larger grains. There is a very limited market for slimed graphite, and in any case there is always some gritty quartz in the flotation concentrate, which is deleterious for the chief purpose for which fine graphite is used, namely, lubrication. Graphite thus falls within the third limitation. Molybdenite is the most easily floated of all the minerals, but a plant of sufficient size to pay a profit on mining and milling would produce enough concentrate in a year to supply the present demand for a hundred years. It is true that a cheap high-grade molybdenite concentrate might build up a new market by making that metal available for new uses, but not at the present price of the concentrate.

The fourth limitation is one for which at present no adequate reason can be given. An ore in which the valuable minerals are wholly or partly bornite or chalcocite, as those of Bingham canyon, will probably give trouble in flotation processes, although not always, for among the many ores tested the one which gave the most uniformly satisfactory results was a copper ore assaying 2.8% copper, all in the form of microscopic specks of bornite. The gangue of this latter ore was an acid dike rock, and it is just possible that the bornite was an original constituent of the rock. There was no appearance in the ore to suggest oxidation, the whole mass being singularly free from fractures. The recovery on this ore was 95%, and the concentrate assayed 48% copper. It may be that only those ores where bornite and chalcocite are of secondary occurrence give trouble. It is true that good hand specimens of bornite, when finely crushed, can be made to float with ease. As a general rule, however, it will be necessary carefully to test copper ores which contain any bornite or chalcocite before pronouncing an opinion as to the probability of successful flotation-concentration. The Bingham canyon ore contains so little bornite or chalcocite that its presence often escapes superficial observation.

SEPARATION OF SULPHIDES.—Up to the present these methods have not with complete success solved the problem of the separation of the sulphides from each other. The sulphides of the base metal have the quality of oil and gas adhesion in varying magnitudes, as can be easily demonstrated, but the range of this variability is much smaller than between gangue and sulphides. No one dare say, however, that even this minute variability does not have in it the basis of a commercial separation. Horwood accomplishes the result by going to the expense of a preliminary slight roast, and thus turning some of the sulphides as far as is necessary into a form analogous to gangue minerals, and destroying the strong adhesive quality of some of the sulphides, and he thereby is able to separate them from those sulphides whose quality of adhesion to oils and gases is unaffected by the slight roast.

This is another of the important unsolved problems, and its solution lies in the direction of combining all the favourable factors in such a way that they all act at the proper time and the proper place. Some oils cause a better frothing of the blende than of the galena; some temperatures are better for the frothing of certain sulphides than of others; some pressures cause a froth to form in which there is a greater proportion of certain sulphides than at other pressures ; the amount of air or gas made available for frothing affects the composition of the froth to a certain extent ; the amount of acid used has a decided influence on the constitution of the froth, and the impurities of the water also have similar effects. The above factors and others, which are available for working in conjunction, conceivably contain the secret of a revolutionary process for solving the long-standing problem of separating completely and commercially mixed sulphides of copper, zinc, and lead. I am inclined to think however, that the solution of this vexed problem lies within the realm of the chemical industry.

COMBINATIONS.—The limitations of any one process of ore concentration are the reasons why metallurgists have always used combinations of processes and of apparatus. We have combinations of hand sorting, jigs, shaking tables, vanners, and many others, and these combinations are further combined with amalgamation, cyanide, chlorination processes, and others. Flotation processes quite properly take their useful places in combinations for the purposes of concentration only, but it is not likely that they will soon be used in combination with the cyanide process ; at least, they will probably not be so used until a successful flotation process is discovered which does not use any acid. We should not at first glance think that health conditions would be good in a plant where cyanide treatment of the ore is either preceded or followed by one of the present flotation processes. Nor is it likely that a combination of an oil-flotation process followed by amalgamation will soon be seen, although there would appear to be nothing to prevent flotation-concentration following amalgamation, provided cyanidation was not desired.

SLIME.—This point will be discussed with some reluctance because the author's past relations have been such that there is a fear he may be charged with favouritism or with advertising a proprietary method. Even at the risk of this criticism it is just to the reader as well as to the process owner to venture a private opinion, based on extended observation. One of the important processes previously described makes no attempt to treat slime, and numerous statements have been made in line with this fact. A second process described, while making, perhaps with some justice, claims of an ability to treat slime, has signally failed in at least two important instances unnecessary to specify. A third now seems to be in a way to overcome its earlier difficulties. Among the minor processes there do not seem to be any which have advanced far in the treatment of slimy material.

The Minerals Separation process has for some years stood alone in its ability to handle with ease in operation, and with commercial profit, the slimiest of mill by-products. This has been demonstrated by operations extending to millions of tons and over years of time. There are sound physical reasons for this feature, and the principles involved—to wit, coagulation of the sulphides, followed by frothing of the coagules—are made the most of. It is unnecessary to give details on the subject of this slime treatment other than are found elsewhere in this and previous chapters. Recent developments of the Potter-Delprat process indicate for certain that slimes can now be treated successfully by this method also.

MAGNITUDE OF OPERATIONS.—It is a significant fact worth keeping in mind that nearly, if not quite, all the plants where these processes are now being used are very large plants. They are treating large tonnages at a small profit per ton, and if they were operating on the scale of the average sized mine, as will appear later, the overhead charges would probably eat up all this profit. In addition to this, the operations are on materials which have already been mined and which cost very little to deliver to the bin. If 10s or 12s per ton for the cost of mining was added to the working cost, the profit would disappear. The cost given later is mostly for the Broken Hill district, where the cost is much higher than is considered necessary elsewhere in the world. It seems probable that the same operations in the United States would be 25% less, even though the cost of materials is about the same and wages much higher than in Australia; on the other hand, labour is doubly efficient and the difference in management beyond the power of figures to express.

ADVANTAGES.—Those ores which have garnet for a gangue-mineral will in general be found particularly amenable to flotation processes, unless a large amount of calcite is also present. Barite gangue is also separated in many instances with ease. Felspar ores are treated with excellent results. Schistose ores, which produce a large amount of slime, will also be found amenable to at least one of the processes. Copper ores, where the sulphides are so finely disseminated as to require crushing to extreme fineness to free the sulphides from the gangue, are the special province of these processes, and they will provide the greatest scope for the future extension of this method of treatment. The ores of the Great Fitzroy mine and the Caucasus Copper company are of this type. Many of the ores where the valuable constituents are in the form of silver sulphide, accompanied by pyrite in a quartz gangue—like the ore of the San Pedro mine, Guanacevi, Mexico—give an excellent separation with high-grade concentrate and good recovery. This class of ore deserves close study in connection with these processes. An ore from Japan, containing gold apparently locked in stibnite, gave good results. This ore yielded scarcely any of its gold content by amalgamation, gravity concentration, or any chemical method ; and required very fine grinding to free the stibnite from the quartz.

An ore from Bolivia, in which the gangue is quartz and garnet, and the valuable content in tetrahedrite, yielded 93% of the gold and silver in small tests in a high-grade concentrate.

BROKEN HILL.—In 1904 it was estimated that there were in the dumps at Broken Hill the following by-products :

Mine.	Material.	Tons.	Assay		
			Zn. %	Pb. %	Ag. oz.
Proprietary	tailing	2,500,000	17.0	4.0	6.0
Block 10	,,	520,000	22.0	6.0	9.5
	middling	137,000	22.5	7.5	10.5
	slime	165,000	18.0	10.0	9.0
Central	tailing	1,000,000	22.0	7.0	6.0
	slime	600,000	21.0	17.0	20.0
South	tailing	620,000	19.7	7.2	4.2
	slime	100,000	18.4	14.6	6.4
Block 14	tailing	250,000	16.5	7.0	6.5
British	,,	250,000	17.0	4.8	5.0
	slime	125,000	21.0	8.9	10.0
Junction	tailing	10,000	19.0	16.0	10.0
	,,	60,000	12.0	7.0	7.0
	slime	25,000	13.0	12.0	12.0
Junction North	tailing	95,000	12.4	10.0	9.0
	slime	5,000	13.0	11.0	12.0
North	tailing	100,000	17.0	8.0	5.0
	slime	20,000	14.0	11.0	11.0
	Total	6,582,000			

The annual production of zinc concentrate by flotation processes since the above estimate was made has been as follows :

	Tons.
1904	57,602
1905	103,532
1906	102,664
1907	236,251
1908	275,932
1909	373,906
1910	468,627
1911	516,378
1912	520,518
1913	407,346
Total estimated	3,062,756

The ratio of concentration on this material has been about 3.6 to 1, so that 11,000,000 tons of material have been treated. There still remains untreated sufficient material to keep the present plants going until 1919, when the accumulated tailing should be exhausted. It is therefore evident that the 1904 estimates of tonnage available were far short of the truth. It is not probable that there will be any further great increase in the annual production of zinc concentrate at Broken Hill. It seems more probable that the pinnacle of tonnage was reached in 1912, and that the production will decrease from now on until the accumulated tailing is finished. There should be no large drop in the total tonnage produced, because the Zinc Corporation, the Amalgamated Zinc, and the Broken Hill Proprietary have reserves of tailing that will last for several years to come. One large plant has ceased operating, but its place was taken by two smaller ones. A steady slow decrease in production may be expected, because most of these companies, during their early struggles with the vagaries of the processes, used their best material to make ends meet. They will probably make as much money out of their lower-grade material as they did out of the higher-grade material. When these immense piles are exhausted, which can be definitely predicted for 1919 or before, there will be a sudden drop in the zinc production of Broken Hill, which should considerably disturb the world's zinc market. The present production of Broken Hill zinc represents just about 20% of the total world's production. It is a remarkable fact that this enormous increase in the production of a district, which seven years ago produced practically no zinc, has caused very little disturbance of the price. This was due to the fact that the high-grade Broken Hill zinc concentrate took the place of low-grade ores from many places in the world, outside of the United States, and these latter low-grade mines simply ceased production because the low-grade material could not compete with the high-grade at the same metal price.

The material treated by these processes at Broken Hill is of comparatively high grade, averaging at present nearly 18% zinc, 6% lead, and 7.5oz. silver per long ton. In spite of these good assays, the profits are not fabulous. After charging working cost, royalty to process owners, smelters' charges, and management, there is left on an average about 12s. per ton treated. In the case of some of the companies this is further decreased by the prices paid to the mining companies for the tailing. The average price for all the tailing and slime sold by the mining companies to the treatment companies averages about 6s. per ton, leaving on an average not over 6s. per ton profit to the treatment companies when zinc is £23 per ton. These are not the actual results of any one company, but are a fair average of the whole. Some of the companies increase this profit in favourable cases by anything up to 4s. per ton through the re-treatment of the flotation-concentrate, by means of which re-treatment a good lead concentrate is taken out of the flotation-concentrate. This lead concentrate represents about 50% of the lead in the flotation-concentrate. These figures mean that if the price of zinc dropped to £20 per ton the flotation plants would have to close down, or else reduce the working cost or economize in some other quarter.

The present selling contracts to the German zinc smelters represent a handsome profit to the latter. It seems certain that every ton of concentrate, which mostly goes to Germany, represents a clear profit to the Germans of at least 40s. per ton of concentrate or 11s. per ton of the original material. From the standpoint of the treatment company, this seems a rather liberal share of profit to the zinc smelter, and it speaks well for the acumen of the Germans that they tied up this large production under long contracts.

Some of the contracts under which this concentrate is sold are represented by the following equations :

(1.) Payment on board cars at Broken Hill =
$(\text{Zn}-8)\ (\text{P}-5\%)+(\text{Pb}-8.5)\ (\text{1s. 3d.})+(\text{Ag}-\text{5oz.})\ (\text{P}'/2)-\text{R}$
Where Zn is percentage assay in zinc.
,, Pb ,, ,, lead.
,, Ag ounces per ton of silver.
,, P is average price of zinc over six months following delivery.
,, P′ is average price of silver over six months following delivery.
,, R is a smelting and freight charge, which is £5 when the price of spelter is £17 10s., and increases 3s. per ton for each £1 increase in the average price, and decreases 3s. per ton for each £1 decrease in the average price.
There is a penalty of 1s. 3d. per unit for every unit of lead under 8%, but the lead penalty is never to exceed the payment for silver.

(2.) Payment on board cars at Broken Hill =
$(\text{Zn}-8)\ (\text{P}-5\%)+(\text{Pb}-8)\ (\text{1s.})+(\text{Ag}-\text{5oz.})\ (\text{P}'/2)-\text{R}$
Where Zn is percentage assay in zinc.
,, Pb ,, ,, lead.
,, Ag ounces per ton of silver.
,, P is average price of zinc during six months of delivery.
,, P′ is average price of silver during six months of delivery.
,, R is a smelting and freight charge, which is £5 17s. 6d. with spelter at £23, and increases 2s. 6d. per ton for each £1 increase in the average price, and decreases 2s. 6d. per ton for each £1 decrease in the average price.
There is a lead penalty of 1s. 6d. per unit for each unit under 5%.

ROYALTIES.—The average royalty charged by the process owners for the use of these flotation processes is one shilling per ton of ore treated. This is very high royalty as measured by others with which miners and metallurgists are familiar. It is conceded that the inventor deserves compensation for his ingenuity, but 1s. per ton is about four times as large a royalty as the mine manager would expect. Large royalties have the disadvantage that they place a premium on infringement, and for this reason alone are, from the standpoint of the process owner, not good business. The combined capital of all the companies owning flotation processes is nearly £1,000,000. This means that 20,000,000 tons of ore will have to be treated and pay royalty of 1s. per ton before the capital is returned. These companies have been in existence now about ten years, and if we consider that the investment ought to yield 10%, then the processes should have treated to date, besides the above tonnage, 20,000,000 tons more, making a total of 40,000,000 tons, which should have been treated to date. They are still about 20,000,000 tons behind. This does not mean anything particular, except that as a class these process companies were considerably over-capitalized, and have also wasted their money, both revenue and capital, on expensive litigation.

WORKING COST.—Figures on cost and recovery, owing to entirely unnecessary secrecy on the part of some of the companies, are not to be secured in the ordinary manner. But there are few secrets* which do not yield to the cruel analysis of the mathematical equation, assisted by scraps of evidence which can be collected in the broad light of day. By these means and the published returns of those who are proud of their work, a fairly correct summary of the whole position can be made as to the treatment of Broken Hill zinkiferous tailing. The following is a general average of all the processes :

	s.	*d.*
Tramming to plant		6
Re-crushing	1	8
Flotation treatment	3	7
Handling concentrate		6
Handling residue		6
Re-treatment of concentrate ..	1	6
Royalty	1	0
Total	9	3

Of these figures the only one which needs discussion here is the general average of 3s. 7d. for the flotation treatment, and it will be interesting to compare the cost of different processes in this particular. These figures do not exactly correspond to those given in previous chapters, because certain items have been reduced to a comparative basis by using one price for the respective materials used.

***The Mining Magazine*, August, 1910, 'Percentages of Recovery.'

Item.	Potter-Delprat.		De Bavay.		Elmore.		Minerals Separation.	
	s.	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*
Power		.90		1.50		1.34		1.74
Acid	1	3.00		8.00	1	0.90	1	0.15
Oil				6.00		6.00		6.00
Supplies		6.00		6.00		6.87		5.50
Labour		2.00	1	0.00		5.68		2.22
Fuel for heating		6.00						5.42
Assays		.30		.30		.38		.30
Water		1.50		1.50		1.99		1.50
General expense		8.72		8.72		8.72		8.72
Total	3	4.42	3	8.02	3	7.88	3	7.55

Power.—In the Potter-Delprat process this figure is for pumping and circulating the acid liquor. As a power charge it is confused to some extent with upkeep of pumps, which is a greater item than it would be if the pumps were handling only water. In the De Bavay the power charge includes the washing of the pulp, mixing with the oil, and elevation of the pulp. In the Elmore the charge includes mixing, the vacuum, and elevation. In the Minerals Separation it includes mixing and aeration by means of violent agitation, and also elevation of the pulp, and in this process the power charge will always be one of the largest. In theory it accomplishes the act of flotation by the direct expenditure of energy.

Acid.—The acid cost is obtained by an indirect method. In the Government reports the tons of acid produced in the year are given, and it has been assumed that it was all used in some of the flotation processes. It is possible that some of the De Bavay or Elmore acid should be charged to Minerals Separation. The error, however, is not large.

Oil.—The Potter-Delprat presumably uses no oil, and this, together with the low labour cost, gives that process a definite lead over all the others. The De Bavay uses a comparatively expensive oil in considerable quantity. The Elmore uses a cheap oil in comparatively large quantity, and Minerals Separation uses a very expensive oil in small quantity.

Supplies.—The item for supplies other than oil, acid, fuel, and water will be just about the same in all the plants. The Potter

Delprat has a considerable bill for renewal of boxes ; the De Bavay extends over a wide area ; the Elmore has the most machinery ; and the Minerals Separation must renew the mixing devices.

LABOUR.—Considering the simplicity of operations, this cost is excessive when measured by general practice, the general inefficiency of Broken Hill labour, coupled with its high cost, being responsible. The figures given are thought to be reasonably correct for each of the processes, but may contain some error. The Potter-Delprat takes the least number of men to operate ; the De Bavay covers a wide area and requires close attention ; and the Elmore requires more men than either the Potter-Delprat or Minerals Separation.

FUEL FOR HEATING.—The Potter-Delprat process is conducted at a higher temperature than any of the others. The De Bavay operates at the normal temperature, as does generally the Elmore also. The Minerals Separation uses 60° to 70° C.

ASSAYS.—This is a comparative charge, and should not differ in any of the processes ; some of them may have no assay charge.

WATER.—Water at Broken Hill costs 5s. per 1,000 gallons. The loss per ton by unreclaimed water in the residue will be almost identical in each case, as the methods of reclaiming water are similar, being by way of settlement first in tanks until sufficiently dry to travel on a belt or be handled in trucks. The losses by leakage and evaporation should be about the same in each case.

GENERAL EXPENSE.—This charge, being accurately known in one case, is assessed for purposes of comparison to all of the processes at the same figure. There is really a big difference, but this difference is not inherent in the process ; some of the plants are managed efficiently for half the cost of the bad management in others.

CONCLUSIONS.—There is not much to choose between the working costs of the four. The advantage which any one process may have over the others lies in the comparative recovery, grade of concentrate, cost of plant, and general applicability. The working cost of treating copper ores will be about 25% less than the figures given, because less concentrate is handled and less acid in general is used. In spite of the fact that the general average of treatment cost is approximately 4s. per ton in the plants studied, I think that under the efficient management that is given to American mines, and with an efficiently designed plant and properly chosen process, a working cost of 2s. per ton is easily within reach. The royalty of 1s. per ton does not seem imminently reducible.

As a demonstration of the utility of the invention, we may say, then, that it has already added to the world's wealth nearly 1,000,000 tons of spelter, 100,000 tons of lead, 20,000,000 oz. of silver, and 5,000 tons of copper ; and at the present rate is adding yearly 200,000 tons of spelter, 20,000 tons of lead, 5,000,000 oz. of silver, and 1,000 tons of copper.

It has pushed well forward the solution of the difficult problem of the recovery of valuable metals from worthless products and low grade ores, and has also placed the metallurgist directly or indirectly within striking distance of the solution of his most difficult task, the separation of lead and zinc.

CHAPTER XII.

BIBLIOGRAPHY.

The literature of the flotation process is about 10 years old. The published articles have not been many, and what has been published has not been particularly informing. There has been an effective effort on the part of the companies owning the patents to suppress details, because of a groundless fear of competition and of new inventions not owned by themselves. The one exception to this line of policy has been that of the Elmore companies, who have from the very first been quite open in their communications to the public. Whether the other process companies have been wise from a money-making standpoint is their affair. There is no doubt, however, that the development of the art has been seriously delayed, and the industry is thereby the loser. No papers deserving special mention have been published. The few descriptions of plant and processes that exist are of about the same merit. Most of the important papers on the theory of capillary action, surface tension, and adhesion have also been included in the bibliography. Of these the article in the *Encyclopædia Britannica* is the most important.

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p. 273, Minerals Separation process.
p. 305, Zinc Corporation, Ltd.
p. 421, ditto.
p. 562, ditto.
p. 55, Apparatus for flotation.
p. 253, Flotation processes.
p. 556, ditto.
p. 177, ditto.
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p. 2, Flotation-concentration, ¼ col.
p. 4, Patent, Gillies.
p. 50, Potter *v.* Delprat, ½ col.
p. 80, Flotation process, ⅔ col.
p. 100, Potter *v.* Delprat, 9 lines.
p. 109, De Bavay process, 1 col.
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p. 358, Zinc Corporation and the processes, ½ col.
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p. 529, De Bavay Treatment Co., ¼ col.
p. 550, Patents, Sulman, Picard, and Ballot.

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p. 34, Zinc Corporation, 4 lines.
p. 50, The Australian Flotation Processes, 1 col.
p. 78, Flotation Processes, 2 col.
p. 122, Potter *v.* Broken Hill Proprietary, 1 col.
p. 126, Zinc Corporation, Elmore and De Bavay, 7 lines.
p. 127, Central mill, ¼ col.
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p. 217, Elmore, 5 lines.
p. 218, Zinc Corporation, 10 lines.
p. 225, Potter's Sulphide Process, 1 col.
p. 241, Zinc Corporation, ¼ col.
p. 243, Patents, Sulman.
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p. 269, ditto, 1½ col.
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p. 344, ditto, ¼ col.
p. 364, Patent, De Bavay.
p. 366, Flotation processes, 1 col.
p. 436, De Bavay Sulphide Process Co., ¼ col.

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p. 498, Zinc treatment processes, ⅔ col.
p. 521, Zinc Corporation, ¼ col.
p. 525, De Bavay, ¼ col.

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p. 74, Ore Separation, illustrated, 1½ col.
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p. 167, Mount Lyell and Zinc Corporation, ½ col.
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p. 220, Report on Broken Hill Proprietary, ½ col.
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p. 240, Sulphide Corporation production.
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p. 379, Zinc Corporation, ¼ col.
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p. 584, ditto, 5 lines.
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p. 616, Ore Concentration Co., 1¼ col.
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- p. 645, Patent, Wolf.
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- p. 812, Zinc Corporation profits, ¾ col.
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- p. 380, Elmore plant, 5 lines.
- p. 551, De Bavay Treatment Co., 17 lines.
- p. 725, De Bavay Flotation Process, ¾ col.
- p. 766, Litigation, Minerals Separation *v.* Elmore, ½ col.
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- p. 54, 'Progress and Problems in Ore Dressing', Courtenay De Kalb, 1 col.
- p. 232, Sulphide Corporation, ½ col.
- p. 366, Broken Hill processes, 20 lines.
- p. 533, Elmore process, 12 lines.
- p. 563, San Francisco del Oro, 1 col.
- p. 699, Broken Hill Proprietary, ½ col.
- p. 806, Flotation processes, 1 col.

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- p. 123, Broken Hill Proprietary, 20 lines.
- p. 185, Great Fitzroy, ½ col.
- p. 280, Broken Hill, ½ col.
- p. 527, Editorial, flotation processes, 5 lines.
- p. 547, Broken Hill processes, ½ col.
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- p. 15, 'Zinc Production in Australia', Edward Walker, 3 pp., illustrated.
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- p. 240, Litigation against Theodore Hoover by Minerals Separation, 7 lines. Notes on application of flotation processes, 1½ col.
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- p. 703, Flotation patents, $\frac{1}{2}$ col.
- p. 797, Elmore process, $\frac{1}{2}$ col.

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- p. 45, Murex process, $\frac{1}{4}$ col.
- p. 125, New South Wales decision, $\frac{1}{4}$ col.
- p. 177, Murex, $\frac{1}{2}$ col.
- p. 181, Butte and Superior, 4 lines.
- p. 208, New flotation process at Butte, $\frac{1}{4}$ col.
- p. 304, Macquisten, $\frac{1}{4}$ col.
- p. 393, Butte and Superior, 20 lines.
- p. 556, Eucalyptus oil for flotation, 1 col.
- p. 586, Purifying water by coagulation, 1 col.
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- p. 782, Caucasus Copper Co., $\frac{1}{2}$ col.
- p. 809, 'Tube Concentrator', W. A. Scott, $\frac{1}{2}$ col.
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- p. 17, Elmore *v.* Sulphide Corporation, 6 lines.
- p. 18, Broken Hill Companies, 23 lines.
- p. 57, Broken Hill, 1 col.
- p. 319, Butte and Superior, 5 lines.
- p. 323, Butte and Superior—Hyde's plant, 5 lines.
- p. 327, Minerals Separation Ltd., $\frac{1}{3}$ col.
- p. 350, Oil flotation processes, 2 cols.
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- p. 587, 'Progress of the Zinc industry', 2 cols.
- p. 637, De Bavay—Minerals Separation, 1 col.
- p. 706, Hyde process, $\frac{1}{2}$ col.
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- p. 717, 'Flotation of Zinc ores', C. T. Durell, $1\frac{1}{4}$ col.
- p. 879, Viscount Inouye and flotation, 11 lines.
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- p. 12, 'Flotation of Minerals', Kenneth A. Mickle, 5 cols., ill.
- p. 124, Butte and Superior, $\frac{1}{4}$ col.
- p. 153, Zinc Corporation, $\frac{3}{4}$ col., ill.
- p. 162, Advertisement of Minerals Separation process, 1 p.
- p. 218, Broken Hill, $\frac{1}{4}$ col.
- p. 313, Butte and Superior, $\frac{1}{4}$ col.
- p. 314, Braden Copper Company, 12 lines.
- p. 349, Butte and Superior, $\frac{1}{4}$ col.
- p. 355, Broken Hill, $\frac{1}{2}$ col.
- p. 375, Elmore plant at Sulitelma, 3 lines.
- p. 408, Braden Copper Company, $\frac{1}{2}$ col.
- p. 444, Butte and Superior, 10 lines.
- p. 547, Broken Hill Proprietary, $\frac{1}{2}$ col.
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- p. 560, Broken Hill, $\frac{1}{4}$ col.
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- p. 636, Braden Copper Company, 10 lines.
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p. 351, J. D. Wolfe, 5 lines.
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p. 551, Zinc Corporation, Ltd., 1 col.
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p. 761, Bibliography, 18 lines.
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p. 915, Selective flotation, ⅔ col.
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p. 29, Flotation process, 2 lines.
p. 104, Ore treatment at Broken Hill, 1½ pp., ill.
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  - p. 98, Patents, Sulman, Picard, and Ballot.
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  - p. 273, Sulphide Corporation, 10 lines.
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  - p. 356, Patent, Hoover.
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  - p. 395, Zinc Corporation, De Bavay, 20 lines.
  - p. 544, Zinc concentrate, 15 lines.
  - p. 565, Murex Magnetic Process, 1 page, illustrated.
  - p. 575, Zinc Corporation, 8 lines.
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  - p. 3, Junction, one-fifth col.

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p. 506, Patents, Sulman and Picard.
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p. 887, Amalgamated Zinc, 16 lines.
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p. 1100, Zinc Corporation, 20 lines.

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p. 1184, Sulphide Corporation, 10 lines.
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- p. 1237, Murex process, 20 lines.
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- p. 1501, Murex process, 10 lines.
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- p. 1535, Minerals Separation, Ltd., 4 pages.

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- p. 6, Zinc concentrate, 1½ col.
- p. 61, Amalgamated Zinc, 4 lines.
- p. 156, Patent, Nutter.
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- p. 211, Broken Hill Zinc, ½ col.
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- p. 326, Zinc Corporation and change of process, 25 lines.
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- p. 488, British Broken Hill Prop. Co., 1½ col.
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- p. 714, Flotation processes, ¼ col.
- p. 748, Flotation processes, ¼ col.
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- p. 816, New flotation process at Butte, ½ col.
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- p. 889, New flotation process on the Proprietary mine, ¼ col.
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- p. 931, Use of eucalyptus oil, ¼ col.

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- p. 969, Potter process, 15 lines.
- p. 1039, Broken Hill production, ¼ col.

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  - p. 1062, Patent, Lockwood.
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  - p. 1093, Pinnacles mine, 5 lines.
  - p. 1094, Butte and Superior, $\frac{1}{4}$ col.
  - p. 1158, Patent, Minerals Separation, Ltd.
  - p. 1212, Patent, Lockwood.
  - p. 1253, Broken Hill notes, $\frac{1}{4}$ col.
  - p. 1256, Litigation, Minerals Separation *v.* James M. Hyde, $\frac{1}{4}$ col.
  - p. 1299, Report of Minerals Separation, 5 pages.
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  - p. 5, Australian Notes, $\frac{1}{4}$ col.
  - p. 21, Everson-Froment process, 5 lines.
  - p. 38, Metal production, $\frac{1}{2}$ col.
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  - p. 402, The Leuchner process, $1\frac{1}{2}$ cols.
  - p. 670, Patent, Incker.
  - p. 642, Patent (14273), Higgins.
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  - p. 346, Butte and Superior, $\frac{1}{4}$ col.
  - p. 360, Minerals Separation Ltd., 1 col.
  - p. 408, Amalgamated Zinc and Great Fitzroy, Ltd., $\frac{1}{4}$ col.
  - p. 426, Amalgamated Zinc, Ltd., $\frac{1}{4}$ col.
  - p. 508, Amalgamation of interests, 10 lines.
  - p. 553, Murex process, 12 lines.
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  - p. 764, Patent, Murex Magnetic and Lockwood.
  - p. 796, Braden Copper and Minerals Separation, Ltd., 12 lines.
  - p. 806, 'The Flotation Method of Ore Reduction; its evolution and importance in modern mining', $\frac{3}{4}$ col.
  - p. 821, Minerals Separation and De Bavay's Processes Australia Proprietary, Ltd., $\frac{1}{3}$ col.
  - p. 827, Butte and Superior, $\frac{1}{3}$ col.
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  - p. 900, Zinc possibilities at Butte, $\frac{1}{2}$ col.
  - p. 920, Butte and Superior, $\frac{1}{4}$ col.
  - p. 936, Patent Murex Magnetic Co. and Lockwood, 2 lines.

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  - p. 1099, Great Cobar, 3 lines.
  - p. 1131, Patent, Broadbridge, Howard, and Minerals Separation.
  - p. 1181, Murex Plant at Whim Well, 8 lines.
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  - p. 1301, Minerals Separation, Ltd., Annual Meeting, $1\frac{1}{2}$ pp.
  - p. 1304, Review, 'Concentrating Ores by Flotation', Theodore J. Hoover, $\frac{1}{2}$ col.
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  - p. 62, Patents, Chapman and Tucker.

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- p. 101, 'The Murex Process in Germany', Otto Falkenberg, 1 p., ill.
- p. 102, Patents, Sulman, Picard and Minerals Separation, Ltd.
- p. 136, Minerals Separation, Ltd., *v.* James M. Hyde, ¼ col.

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- p. 374, Butte and Superior, 17 lines.
- p. 448, Lyster process at Zinc Corporation Works, 17 lines.
- p. 448, Minerals Separation, Ltd., *v.* James M. Hyde, ⅓ col.
- p. 470, Minerals Separation by Froth, 1½ cols.
- p. 474, Patent, Schick.
- p. 477, Minerals Separation, Ltd., *v.* Hyde, 9 lines.
- p. 477, Hyde process, 3 lines.
- p. 520, Patent, Greenway and Lowry.
- p. 521, Flotation processes at Broken Hill, 1 col.
- p. 544, Patent, Lyster.
- p. 554, Minerals Separation froth agitation process, 8 lines.
- p. 554, Minerals Separation, Ltd., *v.* James M. Hyde, 8 lines.
- p. 599, Lyster process, 2 lines.
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- p. 607, Minerals Separation, Ltd., notice of meeting, 1¼ cols.
- p. 653, Patent, Bradford.
- p. 662, Bradley process, 14 lines.
- p. 678, Patent, Chapman, Tucker and Minerals Separation, Ltd.
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- p. 800, Minerals Separation, Ltd., *v.* James M. Hyde, ½ col.
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p. 56, 'Treatment of Complex Sulphides', Donald Clark, 3 pages, illustrated.
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- p. 201, Broken Hill production, ½ col.
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- p. 32, Zinc Corporation, 1 col.
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- p. 156, Murex, 12 lines.
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- p. 165, Potter, 5 lines.
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- p. 275, Broken Hill flotation processes, 3 col., illustrated.
- p. 320, Zinc Corporation, 10 lines.
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- p. 63, 'Separation of Zinc and Lead Sulphides in Slime' by flotation processes, ½ col.
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- p. 792, Flotation processes in Mexico, ½ col.
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- p. 807, Patent, Hoover.
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CHAPTER XIII.

(1914–1916.)

HISTORICAL.

When the previous edition of this book was written the information available as to Mrs. Carrie J. Everson and her connection with flotation inventions was such as could be culled from various newspaper items published at the time of her attempts to apply her patents. Too much credence was probably given to these newspaper accounts. Recently a committee of Denver engineers has made every effort to clear up the doubtful tales and to take steps to establish a suitable memorial to an early discoverer of a valuable metallurgical method. Under the capable activities of this committee, and especially of its chairman, Mr. George E. Collins, it has been quite clearly demonstrated, from the evidence in the hands of the committee, that Mrs. Everson was not the inventor of the processes described in her patents, but that her husband, Dr. Everson, was the real inventor. The patents were taken out in his wife's name for sufficient financial reasons. It seems a fair inference from the evidence that Dr. Everson was an able man, and if he could have lived to follow up his invention its whole history would probably have been different. Mrs. Everson seems to have fallen into the hands of promoters when she had need of sound technical advice.

The Everson patents have been widely discussed in the technical journals and before the Law Courts. In these quarters, where emphasis is placed on a warning not to read into these patents knowledge acquired subsequent to the date of Everson's invention, there is a lamentable lack of candour in the attempts to limit the patent to the first of two distinctly described methods. The first method described in this patent contains little of interest or importance in its bearing on the historical sequence of the invention; but it is invariably the method which is cited as a proof of lack of anticipation. A patent document is generally a long and tedious study, and it would seem that most of the critics only waded half way through this one. The second method described by Everson should be read by itself, and so read alone cannot but produce a profound impression of discovery and priority in all that is essential to the art.

LITIGATION.

The progress in this direction is marked by two actions. We left the position in Chapter III. where the Circuit Court of Appeals in the United States had pronounced a unanimous judgment in favour of James M. Hyde in the suit brought against him by the Minerals Separation, Ltd. This case has now been appealed to the Supreme Court of the United States, where it is still pending, and will probably remain there for some months.

A new suit has been brought by the Minerals Separation, Ltd., against the Miami Copper Company in New Jersey. The case was carefully tried with the introduction of a great deal of new evidence of a technical nature, together with a thorough consideration of all the points involved. No decision has yet been given in this case.

These two cases are of more interest to the metallurgical industry than any which have hitherto been before the Courts, as they are, in fact, the first law-suits which bring all of the prior patents, or nearly all, into consideration. It is also the first law-suit which places the Minerals Separation Company in the position of actively seeking to establish the validity of its patents against all users. Heretofore that Company had simply acted on the defensive. It remains to be seen whether the offensive can be as successfully conducted as the defensive.

THEORIES OF FLOTATION.

The bearing of electro-statics on flotation has been discussed* in an edifying manner by many writers, and although there is at present no other explanation of some of the phenomena with which we are dealing and no definite conclusion can yet be drawn, the theories propounded are unsatisfactory. The function of acid in the many cases where it is absolutely essential to success has some further explanation by an appeal to electro-statics. Ralston, Block, Callow, Bains, Norris, Durell, and Fahrenwald in the papers referred to have written with exceptional ability and clearness.

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* Oliver C. Ralston, Why do Minerals Float? *Mining and Scientific Press*, Oct. 23, 1915.
James A. Block, Why is Flotation? *Mining and Scientific Press*, Oct. 30, 1915.
J. M. Callow, Notes on Flotation, *Bulletin* of American Institute of Mining Engineers, No. 108, Dec., 1915.
Thomas M. Bains, Jr., The Electrical Theory of Flotation, *Mining and Scientific Press*, Nov. 27, 1915, Dec. 11 1915.
Dudley H. Norris, Molecular Forces in Flotation, *Mining and Scientific Press*, Feb. 12, 1916.
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A great deal of nonsense has been written about viscosity, and one author emphatically promulgates the erroneous statement, among many others, that acid is not essential to successful flotation concentration. This statement, if followed by beginners in the study of flotation, would lead to failure and disappointment. It has been well known for years to the real users of flotation processes that some ores can be successfully concentrated without the use of any acid. Some ores can, in fact, be treated in an alkaline circuit; but a majority of ores cannot, at the present state of our knowledge, be concentrated without the use of decidedly acid liquors. The reason of this and the discovery of a method of obviating the necessity were among the tasks set for research in the previous editions of this book. Some progress has been made toward a solution of the problem set for investigators, but complete elimination of the expense and trouble of using acid has not yet been obtained, if indeed it is either desirable or necessary in all cases.

The divergent views as to what the flotation process is, how it works, and what it can do, arise from matters to which attention was called in previous pages. The most important of these is the variable behaviour of different ores when tested under identical conditions. The metallurgist on a mine in Mexico says: "The best results can be secured with flotation concentration in an alkaline circuit." The metallurgist in New South Wales says: "The best results can be secured with flotation concentration by the use of fifteen pounds of acid per ton." The difficulty with both metallurgists is their lack of exact scientific accuracy. They should both have inserted the words "on this ore" immediately after the word "results."

G. D. Van Arsdale* has given some excellent results of his investigation of surface films and contact angles, and brings the solution of a number of hitherto unsolved problems measurably

* *Engineering and Mining Journal*, May 13, 1916, p. 851.

nearer. Without detracting in the least from the merit of his work, or in any way depreciating his discoveries, it is only right to say that these things and many others of equal, if not greater, importance to science have been discovered and clearly and definitely quantified by H. L. Sulman and H. F. K. Picard. As mentioned in the preface to the first edition, they have for years been working on the physical factors involved in flotation processes, and have had for many years a voluminous work completed and ready for publication.

This manuscript is among the archives of the Minerals Separation, Ltd., who adopt the attitude in this case of censors. If it is the intention of this Company to regard themselves as being in a state of war against the whole metallurgical industry, there might be some justification for an embargo on the publication of scientific information ; but they have received at the hands of the State a valuable monopoly in a great industry, against which they should not wage war ; but, on the contrary, they should act with frankness and candour toward those with whom they seek to do business, and from whom they expect to draw the revenue assured to them by their monopoly.

TESTING ORES.

A large amount of research work of excellent quality has been accomplished at the Salt Lake station of the United States Bureau of Mines, co-operating with the University of Utah. O. C. Ralston, assistant metallurgist of the Bureau of Mines, and Glenn L. Allen, Research Fellow of the University of Utah, have given careful consideration to the matter of laboratory testing. After reading Chapter V. of this book the reader cannot do better than consult their preliminary paper, published in the *Mining and Scientific Press*, January 1 and 8, 1916. The paper is well written and illustrated, and contains many suggestions which represent the added experience gained since the previous editions of this book were issued.

A recent letter from H. J. Stander (of the Arizona State Bureau of Mines) conveys the information that he is writing a text book on flotation, which is intended primarily for college use. This, when it appears, will be a valuable assistance in the testing department.

The most fertile lines for future investigation, aside from tests directed toward adapting the process to specific ores, would seem to be along the following lines :

1. To determine the effect of various substances now known to be frothing agents, and all their allied derivatives, with a view to the widest possible application of their selective flotation qualities between the different sulphides.
2. To determine the effect of variations in method and materials now known to be efficient, with a view to finding means to economize in acids, oils, and gas. A promising line of research with regard to effecting economies in oils is suggested under the heading, ‘ Soluble Frothing Agents ’ in this chapter.

SELECTIVE FLOTATION.

The surface reactions of minerals vary with their chemical composition. This basic fact underlies all the attempts to separate one sulphide from another by flotation. These variations in the surface reactions of sulphide particles are slight when compared with the difference there is between the surface reactions of sulphides and oxides or carbonates.

Cattermole in his early patents had a clear idea of the possibilities of a preferential flotation between the sulphides, but the means he proposed were not effective in practice.

Horwood.—The first effective method was that proposed by Horwood. This method has been in operation at Broken Hill for two years. The results obtained during a typical period of twelve months are given in Table A (page 260). The costs of operation over the same period are given in Table B which will be found on pages 262 and 263.

Wentworth and Ramage also took out patents practically identical with Horwood's, but Horwood's patents bear the earliest date ; and he is, therefore, entitled to the credit of being the inventor.

Lyster.—Lyster's invention has been in use at Broken Hill for two years, with the results during a typical period of twelve months as given in Table C (page 261). The costs of operation over the same period were as given in Table D which will be found on pages 264 and 265.

TABLE A.—HORWOOD PROCESS.

	Aug. 1913.	Sept.	Oct.	Nov.	Dec.	Jan. 1914.	Feb.	March.	April.	May.	June.	July.	Average	Recoveries.
Feed to Roaster.														
Tons	1000	1117	1072	1281	1156	1503	1344	1122	1192	1282	1359	1340	1230.6	100%
Zn. %	36.9	38.4	38.1	38.3	39.5	38.6	38.5	40.4	40.9	39.9	39.7	38.9	39.0	100%
Ag. ozs.	24.0	25.5	25.3	22.7	19.9	24.0	24.1	22.9	20.5	22.6	22.2	22.2	23.0	100%
Pb. %	17.1	16.6	17.4	16.4	15.3	15.8	15.6	14.6	13.9	14.1	13.4	14.6	15.3	100%
Zn. Con. Produced.														
Tons	593	716	649	891	798	862	849	738	775	799	842	867	781.6	63.5%
Zn. %	45.7	47.3	47.6	46.5	47.0	47.7	47.5	48.0	48.9	48.4	47.7	48.5	47.6	77.5%
Ag. ozs.	17.7	18.1	17.7	16.5	13.5	17.6	18.0	18.0	14.7	17.0	16.0	16.9	16.8	46.4%
Pb. %	11.2	10.7	9.8	9.5	8.0	7.8	7.7	6.5	6.1	7.4	5.9	6.8	8.0	33.2%
Leady Res. Produced.														
Tons	329	346	381	332	296	460	430	320	303	291	383	380	354.2	28.8%
Zn. %	20.3	19.3	18.6	13.5	17.2	12.5	15.7	15.0	14.4	11.6	14.4	14.1	15.5	11.5%
Ag. ozs.	38.4	43.6	41.0	40.7	42.3	41.8	42.2	42.7	38.0	40.4	39.3	39.2	40.8	51.1%
Pb. %	29.9	32.0	33.3	36.8	36.6	35.6	34.0	36.2	39.1	39.2	32.9	34.2	34.8	65.5%
Total Percentage Loss of Metal.														Total Recoveries.
Zn. %	8.4	5.5	7.0	6.4	6.7	19.1	9.1	11.0	13.6	17.7	15.3	9.0	11.0	89.0%
Ag. ozs.	3.8	1.8	0.0	2.9	+1.2	3.5	+3.2	+4.7	6.6	12.6	5.4	0.9	2.5	97.5%
Pb. %	3.6	1.6	+2.2	1.2	2.8	2.4	1.9	0.0	+0.1	4.1	3.7	3.5	1.3	98.7%
Tons	78	55	42	58	62	181	65	64	114	192	134	93	94.83	

The costs of operation over the same period are given in Table B.

TABLE C.—LYSTER PROCESS.

		July, 1913.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1914.	Feb.	March.	April.	May.	June.	Average
Feed.	Tons	1641	1280	1283	1374	1299	1126	1148	1292	1371	2191	2194	2021	1518.3
	Zn. %	9.3	9.3	8.8	9.6	10.6	10.3	8.8	8.7	9.6	10.8	10.4	10.4	9.8
	Ag. ozs.	2.8	3.0	2.8	2.6	3.1	3.1	3.3	3.1	3.5	2.4	2.2	2.7	2.8
	Pb. %	14.1	15.0	13.0	13.4	16.1	15.0	14.4	15.8	16.0	11.5	11.3	12.2	13.7
Concentrate.	Tons	357	286	225	251	306	245	257	300	304	334	327	330	293.5
	Zn. %	8.0	7.4	6.8	6.8	7.6	6.4	6.6	6.1	6.8	8.2	7.0	6.8	7.1
	Ag. ozs.	9.4	10.2	10.3	10.1	10.7	10.4	10.4	10.1	11.2	10.3	9.0	10.8	10.2
	Pb. %	55.7	56.9	57.6	56.9	57.7	55.9	50.6	57.8	57.1	53.5	56.7	54.0	55.8
Residue.	Tons	1284	994	1058	1123	993	881	891	992	1067	1857	1867	1691	1224.8
	Zn. %	10.0	9.9	9.2	10.2	11.5	11.3	9.4	9.3	11.1	11.1	11.0	11.1	10.5
	Ag. ozs.	1.0	1.0	1.2	0.9	0.9	1.0	1.2	1.0	1.3	1.0	1.0	1.1	1.0
	Pb. %	2.5	3.0	3.2	3.8	3.4	3.7	4.0	3.2	4.3	4.0	3.2	3.9	3.5
Recovery.	Ag. ozs.	72.5	75.4	65.5	70.4	79.2	75.1	70.8	75.7	70.7	66.3	61.5	66.6	70.4
	Pb. %	86.1	84.6	77.5	77.7	84.2	80.9	78.8	84.9	78.8	70.7	75.2	73.0	78.6

The costs of operation over the same period were as given in Table D.

TABLE B.—HORWOOD PROCESS.

Working Costs, July 1913 to June 1914.

	July		August		September		October		November		December		January	
	Tons handled	281	Tons handled	643	Tons handled		Tons handled	547	Tons handled	768	Tons handled	1141	Tons handled	862
	Expenditure	Per ton handled	Expenditure	Per ton handled	Expenditure	Per ton handled	Expenditure	Per ton handled	Expenditure	Per ton handled	Expenditure	Per ton handled	Expenditure	Per ton handled
	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.
Labour & Salaries ...	179 10 6	12 9^{33}	321 3 0	9 11^{87}			230 3 10	8 5	323 7 2	8 5^{05}	467 10 10	8 2^{34}	320 10 1	7 5^{24}
Supplies General ...	19 17 4	1 4^{97}	26 8 11	9^{87}			19 6 5	8^{48}	27 17 10	8^{72}	58 10 2	1 0^{31}	24 6 9	6^{78}
Frothing Medium ...	57 6 0	4 0^{94}	53 6 9	1 7^{91}			38 10 4	1 4^{90}	39 0 3	1 0^{19}	44 4 4	9^{30}	42 16 1	11^{92}
Sulphuric Acid	10 19 10	9^{39}	31 7 6	11^{71}			35 14 8	1 3^{68}	48 14 8	1 3^{23}	58 8 0	1 0^{38}	48 1 11	1 1^{39}
Water other than steam	40 0 0	2 10^{16}	53 10 7	1 7^{98}			40 6 3	1 5^{69}	52 0 9	1 4^{26}	85 0 0	1 5^{88}	48 15 0	1 1^{57}
Heating Solution ...	37 11 3	2 8^{08}	103 12 1	3 2^{67}			54 1 9	1 11^{73}	82 17 3	2 1^{89}	108 5 0	1 10^{77}	81 3 9	1 10^{60}
Fuel other than steam ...	39 17 6	2 10^{06}	52 8 11	1 7^{57}			42 10 10	1 6^{66}	60 17 0	1 7^{02}	97 17 6	1 8^{59}	67 11 4	1 6^{81}
Power	36 18 3	2 7^{53}	31 9 4	11^{74}			39 2 3	1 5^{16}	41 1 8	1 0^{84}	62 5 10	1 1^{10}	42 14 4	11^{89}
Repairs & Maintenance	18 7 6	1 3^{69}	266 3 0	8 3^{34}			231 9 11	8 5^{57}	259 19 2	6 9^{24}	292 15 8	5 1^{59}	261 6 6	6 0^{76}
Sampling & Assaying ...	47 3 5	3 4^{29}	53 12 0	1 8^{01}			22 14 0	9^{96}	32 18 1	10^{28}	48 1 0	10^{11}	32 3 3	8^{95}
Sundries	4 15 10	4^{09}	5 13 5	2^{12}			1 15 6	0^{78}	5 3 1	1^{61}	4 8 7	0^{93}	4 18 1	1^{37}
Royalty	21 1 6	1 6^{80}	48 4 6	1 6			41 0 6	1 6	57 12 0	1 6	85 11 6	1 6	64 13 0	1 6
Totals ... £	513 8 11	36 6^{53}	1047 0 0	32 6^{74}			796 16 3	29 1^{61}	1031 8 11	26 10^{33}	1412 18 5	24 9^{20}	1039 0 1	24 1^{28}

TABLE B—(continued).

	February		March		April		May		June		Totals	
	Tons handled	1344	Tons handled	1122	Tons handled	1192	Tons handled	1282	Tons handled	1359	Tons Handled	10541
	Expen-diture	Per ton hand-led	Expen-diture	Per ton hand-led	Expen-diture	Per ton hand-led	Expen-diture	Per ton hand-led	Expen-diture	Per ton hand-led	Expen-diture	Per ton handled
	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.
Labour & Salaries ...	567 3 1	8 5^{28}	506 6 4	9 0^{30}	593 9 7	9 11^{49}	749 19 10	11 8^{40}	709 16 8	10 5^{34}	4969 0 11	9 5^{14}
Supplies General ...	52 12 5	9^{40}	50 19 0	10^{90}	45 12 2	9^{18}	170 8 5	2 7^{90}	98 13 4	1 5^{43}	594 12 9	1 1^{54}
Frothing Medium ...	58 7 3	10^{42}	52 2 10	11^{16}	40 10 6	8^{16}	83 17 8	1 3^{71}	46 5 2	8^{17}	556 7 2	1 0^{66}
Sulphuric Acid	87 7 6	1 3^{60}	57 12 1	1 0^{32}	65 1 0	1 1^{10}	73 13 7	1 1^{79}	82 18 3	1 2^{64}	599 19 0	1 1^{65}
Water other than steam	81 15 0	1 2^{60}	55 10 0	11^{87}	57 10 0	11^{58}	58 15 0	10^{99}	42 10 0	7^{51}	615 12 7	1 2^{02}
Heating Solution ...	112 14 0	1 8^{12}	106 2 6	1 10^{70}	130 11 3	2 2^{29}	16 15 0	3^{14}	124 12 6	1 10^{01}	958 6 4	1 9^{82}
Fuel other than steam ...	101 15 0	1 6^{17}	85 3 9	1 6^{22}	108 15 0	1 9^{89}	90 12 6	1 4^{97}	119 12 6	1 9^{13}	867 1 10	1 7^{74}
Power	82 6 11	1 2^{70}	115 17 5	2 0^{79}	124 3 5	2 1	152 16 9	2 4^{61}	157 17 5	2 3^{88}	886 13 7	1 8^{19}
Repairs & Maintenance	373 12 11	5 6^{72}	420 3 10	7 5^{88}	366 8 6	6 1^{78}	471 10 5	7 4^{27}	866 14 9	12 9^{07}	3828 12 2	7 3^{18}
Sampling & Assaying ...	52 3 8	9^{32}	58 19 2	1 0^{61}	50 15 1	10^{22}	66 0 5	1 0^{36}	63 6 7	11^{18}	527 16 8	1 0^{01}
Sundries	7 12 0	1^{36}	6 0 11	1^{29}	4 10 1	^{91}	5 12 6	1^{06}	6 0 6	1^{07}	56 10 6	1^{29}
Royalty	100 16 0	1 6	84 3 0	1 6	89 8 0	1 6	96 3 0	1 6	101 18 6	1 6	790 11 6	1 6
Totals ... £	1678 5 9	24 11^{69}	1599 0 10	28 6^{04}	1676 14 7	28 1^{60}	2036 5 1	31 9^{20}	2420 6 2	35 7^{43}	15251 5 0	28 11^{24}

TABLE D.—LYSTER PROCESS.

Working Costs, July 1913 to June 1914.

	July		August		September		October		November		December		January	
	Tons handled	1482	Tons handled	1394	Tons handled		Tons handled	1205	Tons handled	1315	Tons handled	1015	Tons handled	1314
	Expenditure	Cost per ton handled	Expenditure	Cost per ton handled	Expenditure	Cost per ton handled	Expenditure	Cost per ton handled	Expenditure	Cost per ton handled	Expenditure	Cost per ton handled	Expenditure	Cost per ton handled
	£ s. d.	s. d.	£ s. d.	s. d.			£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.
Labour and Salaries ..	114 6 10	1 6^{52}	132 8 6	1 10^{80}			113 3 6	1 10^{54}	119 7 0	1 9^{78}	98 19 10	1 11^{41}	111 8 1	1 8^{38}
Power	14 15 6	2^{39}	14 9 10	2^{49}			15 9 6	3^{08}	12 6 6	2^{25}	14 5 4	3^{37}	16 5 6	2^{97}
Repairs & Maintenance	45 18 6	7^{44}	44 11 7	7^{68}			69 10 6	1 1^{85}	30 12 0	5^{58}	67 1 7	1 3^{86}	83 17 0	1 3^{31}
Assaying	18 2 10	2^{74}	21 4 9	3^{66}			19 3 3	3^{82}	18 19 8	3^{47}	16 15 2	3^{96}	18 9 10	3^{38}
Eucalyptus	48 7 6	7^{83}	36 11 9	6^{30}			42 17 6	8^{54}	42 16 11	7^{82}	35 0 0	8^{28}	39 7 6	7^{19}
General Supplies ...	2 7 1	0^{38}	3 2 11	0^{54}			3 5 10	0^{65}	3 15 10	0^{69}	3 10 8	0^{84}	3 13 1	0^{67}
Royalty							28 15 0	5^{73}	38 10 0	7^{03}	27 7 6	6^{47}	36 12 6	6^{69}
Totals .. £	243 18 3	3 3^{50}	252 9 4	3 7^{47}			292 5 1	4 10^{21}	266 7 11	4 0^{82}	263 0 1	5 2^{19}	309 13 6	4 8^{56}

TABLE D—(continued).

	February		March		April		May		June		Totals	
	Tons handled	1352	Tons handled	1519	Tons handled	2099	Tons handled	2237	Tons handled	2223	Tons handled	17155
	Expenditure	Cost per ton handled	Expenditure	Cost per ton handled	Expenditure	Cost per ton handled	Expenditure	Cost per ton handled	Expenditure	Cost per ton handled	Expenditure	Costs per ton handled
	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.	£ s. d.	s. d.
Labour and Salaries ...	105 14 11	1 6^{77}	113 3 0	1 5^{88}	99 3 9	11^{34}	94 13 5	10^{16}	91 4 7	9^{85}	1193 18 5	1 4^{69}
Power	44 12 9	7^{92}	47 6 3	7^{48}	55 12 6	6^{36}	64 3 0	6^{88}	63 7 8	6^{84}	362 14 4	5^{07}
Repairs & Maintenance	71 9 9	1 0^{69}	83 18 1	1 1^{26}	114 10 6	1 1^{09}	59 9 10	6^{38}	97 0 5	10^{47}	767 19 9	10^{74}
Assaying	16 8 11	2^{92}	18 3 4	2^{87}	20 15 10	2^{38}	18 12 1	2^{00}	22 17 0	2^{47}	209 12 8	2^{93}
Eucalyptus	31 15 10	5^{64}	41 14 2	6^{58}	52 7 8	5^{99}	56 17 6	6^{10}	56 19 10	6^{15}	484 16 2	6^{77}
General Supplies ...	4 13 0	0^{83}	3 17 2	0^{61}	1 14 9	0^{20}	2 18 8	0^{31}	2 19 5	0^{32}	35 18 5	0^{54}
Royalty	39 10 0	7^{01}	39 12 6	6^{26}	39 5 0	4^{49}	41 7 6	4^{44}	44 5 0	4^{78}	335 5 0	4^{68}
Totals ... £	314 5 2	4 7^{78}	347 14 6	4 6^{94}	383 10 0	3 7^{85}	338 2 0	3 0^{27}	378 13 11	3 4^{88}	3389 19 9	3 11^{42}

Lyster's process accomplishes the exact opposite to Horwood's. Horwood makes a froth consisting almost wholly of zinc sulphide ; Lyster makes a froth consisting almost wholly of galena. The solution is kept in a neutral or alkaline condition, and for this reason the method can be used on material containing a high percentage of calcite ; in fact, there is reason to believe that the method as at present carried out can be employed only on substances high in calcium carbonate. This method is the first truly preferential method, as Horwood has to prepare his material for flotation by a preliminary treatment.

The best source of information as to how to carry out the process is Lyster's patent, but it may be briefly described as flotation carried out in a neutral or alkaline pulp, the surface tension of the liquid being modified by having dissolved in it varying proportions of sulphates, chlorides, or nitrates, the modification by these salts being such that galena is selectively floated to the exclusion of other minerals. The apparatus is important.

A number of patents for selection flotation were taken out in Australia, where the chief feature of the invention was the use of a solution of soda ash. Recent investigation has demonstrated that successful results were secured under this method on the ore in question only when a copper vessel was used, and that the result comes not especially from the soda ash, but from the copper which was taken into solution. It is supposed that this copper is re-deposited on the faces of the small fragments of one of the sulphides, and not on the faces of the other, thus rendering one sulphide amenable to flotation while the other sinks. Those who favour the electro-static explanation of flotation concentration may see in this fact some evidence in support of their theory.

CALLOW.

The method* of flotation proposed by J. M. Callow consists of introducing oil and air into the pulp in a vessel similar to a Brown agitator or Pachuca vat, and passing the mixture or emulsion thus obtained into cells having perforated bottoms, through which air is forced upward. The compressed air, as it rises in the form of small bubbles, creates the froth. The first set of cells are the " roughers," in which a crude concentrate is produced. This is afterward sent to " cleaner " cells, where a final concentrate is obtained. After settlement the concentrate is sent to filter presses to be dewatered. The accompanying illustration (Fig. X) gives an outline of the arrangements. The dimensions of the cell are about 9 feet long and 2 feet wide, with a bottom inclined at a slope of 3 to 4 inches to the foot, the depth being 20 inches at the front end and 45 inches at the deeper end. The structure is preferably of wood. The bottom consists of a porous medium made of four thicknesses of loosely woven canvas twill, supported by a backing of perforated metal. Through this porous medium compressed air is forced. The space underneath the porous medium is sub-divided into eight compartments, each connected by an individual pipe and valve with the main air-pipe. By this means the air pressure to each compartment can be regulated by throttling the valve to correspond to the varying hydraulic head within the tank, and so as to discharge a uniform amount of air

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* *The Mining Magazine*, Vol. xiv., 1916, p. 48.

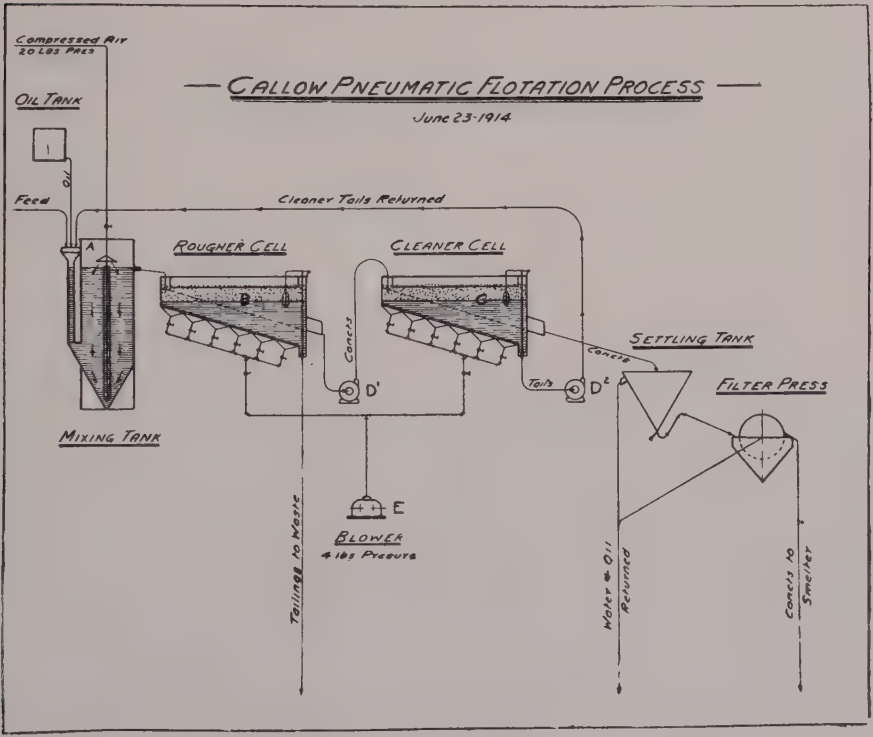

FIG. X.

throughout the length of the bottom and maintain a uniform aeration of the contents. A pressure of from 4 to 5 lb. is generally used, each square foot of porous medium requiring from 8 to 10 cubic feet of free air per minute. Each longitudinal edge of the tank is provided with a lip and an overflow gutter for the reception of the froth to be discharged. The lower end of the tank has a spigot discharge fitted with a plug valve, operated by a float, to maintain a uniform water-level within the tank, and thus in turn maintain a uniform and constant discharge of froth under all the varying conditions of feed supply. The water level may be varied, but it is usually maintained at about 10 to 12 inches below the level of the overflow lips. The tailing is discharged through the spigot, and the frothy concentrate is conveyed by means of side gutters to a pump, and thence to the cleaner cell. The cleaner cell is a machine of the same construction as the rougher. In operation, however, it is usually run with a lower air pressure than that used on the rougher. The tailing from the cleaner is returned by a pump to the original feed, a closed circuit thus being maintained on this portion of the feed. Usually one cleaner serves four roughers. The machines may be run either in parallel or in series without any sacrifice in the capacity for a given number of cells. Recent experience goes to show that on some ores the series treatment gives a slightly cleaner tailing. It is not necessary to extend this arrangement of cells beyond two cells in series. In a heavily mineralized ore this arrangement is decidedly advantageous, and in such a case the rougher concentrate might be of high enough grade to dispense with the cleaning operation. The froth from the second cell in the series might be returned to the original feed in the same way that the tailing is returned from the cleaner when practising a roughing and cleaning operation. A number of such combinations is possible.

The froth continues to form and to overflow so long as the cell is furnished with pulp of the proper consistency, adequately mixed with the right quantity and kind of oil or frothing agent. Measured from the water-level within the cell, the froth produced may be from 14 to 16 inches thick, and will be more or less voluminous, coarse or fine-grained, dry or watery, according to the character of the ore and the kind and quantity of oil introduced. The condition of the froth may be varied by changes in the kind and quantity of oil used and the quantity of air injected. The pulp to be treated may be of varying density, from 2½ of water to 1 of ore, up to 5 or 6 to 1. For a mixture of sand and slime the former ratio is preferable, but for a pure slime mixture (minus 200 mesh) the larger proportion of water is allowable. The particular density is not a matter of as much importance as the supplying of pulp of uniform density, as each variation in the density of the pulp requires a re-adjustment of the oil supply, the quantity of oil necessary increasing in proportion to the increased proportion of the water.

A normal capacity of the roughing cell is 50 tons per 24 hours. This, of course, will vary according to the nature of the ore. In one plant which practises concentration by gravitation previous to flotation, only the fine sand and slime being treated by the latter process, the rate is 50 tons per roughing cell. The Inspiration Copper Company practises flotation as the prime process, each 800-ton section employing 24 roughing cells and four cleaners. The cells in this case are run in series, the primary cells treating the original feed, and the secondary cells treating only the slime from the primary tailing after the sand has been removed. This gives an average of 33.3 tons per roughing cell. The Arizona Copper Company's plant will treat the slime and re-crushed sand from previous gravity treatment; out of an original tonnage of 4,000 about 3,600 tons will be treated by flotation. This will be handled in 63 roughers run in parallel, and 18 cleaners, or an average of approximately 57 tons per roughing cell, or 45 tons per cell for roughing and cleaning. Some tests have shown little difference in recovery when running from 45 tons to the cell or 65, but show that the recoveries commence to decline as soon as the tonnage exceeds 75 tons. In the Cœur d'Alene, on zinc-lead ores, 35 tons per cell is an average capacity.

The oils used may be broadly divided into "frothers" and "collectors." The pine oils are good frothers, and coal tar and its various sub-divisions are good collectors. On some ores crude pine tar will in itself combine the properties both of frothing and collecting; on others this may have to be enriched by the addition of some one of its more volatile constituents, such as refined pine oil, turpentine or wood creosote. Generally speaking, the coal tar products are poor frothers, and to get a sufficient volume of froth to ensure a high recovery it is often necessary to add refined or crude pine oil, creosote, etc. At the Inspiration mill, for instance, the mixture is 80% crude coal tar, 20% coal tar creosote. At another plant on similar ore 45% El Paso coal tar, 40% coal tar creosote, 10% cresol, and 5% pine oil. At Daly-Judge a mixture of 40% crude coal tar, 40% creosote, and 20% pine oil was used. In the Cœur d'Alene on zinc ore straight wood creosote was used, on the ore of the National Copper Mining Company plain turpentine will work, but pine oil is better. At Inspiration from 1½ to 2 lb. of the mixture was used per ton of ore; at Daly-Judge 1 to 1½ lb.; and at the National 0.3 lb. of oil is sufficient. In the experimental work at another plant the oil consumption was approximately 1 lb. of mixture per ton; but since the entire plant has been in operation and the circuit water reclaimed and used over again the oil consumption has dropped to 0.35 lb. At present the proper kind or kinds of oil and the requisite quantity can only be determined by experiment; no scientific way has thus far been found.

The froth made by the Callow process has the distinctive characteristic of being unstable or ephemeral—that is, it quickly dies when removed from the action of the injected air. The bubbles composing the froth are generated under a hydraulic pressure varying from 15 to 40 inches; upon rising above the water to the froth level the bubbles burst by reason of the lower pressure of the atmosphere. On bursting they release the mineral attached to them, which is caught up by the bubbles following immediately beneath. The stability of the bubbles depends, to some extent, upon the oil used and the nature of the gangue in the pulp treated. Pine oil makes a brittle froth, which dies immediately on arriving at the surface. Creosote and light oil make a more elastic envelope, which at times will expand into bubbles 3 to 4 inches in diameter before bursting. Pine oil bubbles are rarely over ¼ or ½ inch in diameter Castor oil, olive oil, candle-makers' oil (oleic acid), palm oil, sperm oil, and other oils of a lubricating nature have in general been replaced by oils more or less soluble or miscible in water, such as turpentine, pine oil, and all the coal and wood tar distillations. The extremely volatile oils, such as naphtha, petrol, ether, and alcohol, seem to be of little use, except as a means for making the pitchy ingredients of coal and wood tars more soluble or miscible. A large, coarse, and elastic bubble seems necessary to the recovery of coarse-grained mineral, but for the very fine and colloidal mineral a small and comparatively brittle bubble is necessary.

APPLICATION.

The tonnage treated by flotation processes has been more than doubled in the years under consideration, the United States and South America being chiefly affected by the extension of their use. The zinc ores at Butte, Montana, have yielded remarkable and hitherto unequalled results. The low-grade copper ores of Montana, Arizona, Mexico, and Chile are all being successfully treated in large tonnages, and in several cases flotation has displaced gravity concentration almost wholly. The following list of new users is more or less complete :

AMERICAN ZINC COMPANY, Tennessee. Zinc ; principal mineral, blende.

ANACONDA COPPER MINING CO., Montana. Copper, silver ; principal minerals, enargite, covellite, chalcocite, pyrite.

ARIZONA COPPER CO., LTD., Arizona. Copper ; principal mineral, chalcocite.

ATLAS MINING & MILLING CO., Colorado. Silver, lead ; principal minerals, tetrahedrite, galena.

M. W. ATWATER, Montana. Zinc, silver ; principal mineral, blende.

BEATSON COPPER CO., Alaska. Copper ; principal mineral, chalcopyrite.

BRITANNIA MINING & SMELTING CO., British Columbia. Copper ; principal minerals, chalcopyrite, bornite.

BUNKER HILL AND SULLIVAN, Cœur d'Alene. Lead ; principal mineral, galena.

BURRO MOUNTAIN COPPER CO., New Mexico. Copper ; principal mineral, chalcocite.

BRADEN COPPER CO., Chili. Copper.

BUTTE REDUCTION WORKS, Montana. Copper ; principal mineral, enargite.

BUTTE & SUPERIOR COPPER CO., Montana. Zinc ; principal mineral, argentiferous blende.

CAUCASUS COPPER CO., South Russia. Copper ; principal mineral, chalcopyrite.

CONSOLIDATED ARIZONA SMELTING CO., Arizona. Copper ; principal mineral, chalcopyrite.

CONSOLIDATED INTERSTATE-CALLAHAN MINING CO., Idaho. Zinc ; principal mineral, blende.

CUBA COPPER CO., Cuba. Copper ; principal mineral, chalcopyrite.

DALY-JUDGE MINE.

DOE RUN LEAD CO., Missouri. Lead ; principal mineral, galena.

DESLOGE LEAD CO., Missouri. Lead ; principal mineral, galena.

DUCKTOWN I. S. & C. CO., LTD., Tennessee. Copper ; principal minerals, chalcopyrite, cupriferous pyrite.

ENGELS COPPER MINING CO., California. Copper ; principal minerals, chalcopyrite, chalcocite, bornite, covellite.

FEDERAL LEAD MINING CO., Idaho. Silver, lead, zinc ; principal minerals, blende, argentiferous galena.

FEDERAL LEAD CO., Missouri. Lead ; principal mineral, galena.

GOLD HUNTER MINING CO., Idaho. Lead, zinc, silver ; principal minerals, blende, galena.

GREENHILL CLEVELAND MINE, Idaho. Lead, zinc, silver ; principal minerals, galena, blende.

HERCULES MINING CO., Idaho. Lead, zinc, silver ; principal minerals, galena, blende.

INSPIRATION CONSOLIDATED CO., Arizona. Copper ; principal minerals, chalcocite, chalcopyrite.

KENNECOTT MINES CO., Alaska. Copper ; principal mineral, chalcocite.

MIAMI COPPER CO., Arizona. Copper ; principal mineral, chalcocite.

MINERALS RECOVERY CO., Missouri. Zinc ; principal mineral, blende.

MOUNTAIN COPPER CO., California. Copper ; principal mineral, chalcopyrite.

MAGMA COPPER CO., Arizona. Copper ; principal mineral, chalcocite.

NATIONAL COPPER CO., Idaho. Copper ; principal mineral, chalcopyrite.

NATIONAL LEAD CO., Missouri. Lead ; principal mineral, galena.

NEVADA CONSOLIDATED COPPER CO., Nevada. Copper ; principal mineral, chalcocite.

OLD DOMINION COPPER MINING CO., Arizona. Copper ; principal mineral, chalcopyrite.

OZARK MINING & SMELTING CO., New Mexico. Zinc, lead ; principal minerals, galena, blende.

PINGREY MINES & ORE REDUCTION CO., Colorado. Lead, zinc, silver ; principal minerals, galena, blende.

SILVERTON MINES, LTD., British Columbia. Silver, lead, zinc ; principal minerals, galena, blende, argentite.

SILVER LAKE MINES, Colorado. Silver, lead; principal mineral, argentiferous galena.

SNOWSTORM MINING CO., Idaho. Copper; principal minerals, bornite, chalcocite, chalcopyrite.

STANDARD SILVER LEAD MINING CO., British Columbia. Lead, zinc; principal minerals, galena, blende.

ST. JOE LEAD CO., Missouri. Lead; principal mineral, galena.

TIMBER BUTTE MILLING CO. (Elm Orlu), Montana. Silver, zinc, copper, lead; principal minerals, galena, tetrahedrite, blende.

UTAH COPPER CO., Utah. Copper; principal minerals, pyrite, chalcocite.

UNITED COPPER MINING CO., Washington. Copper; principal minerals, chalcopyrite, bornite.

The range of applicability of the process has widened appreciably in the last two years. Ores which up to that time had proved recalcitrant, have, with the wider efforts of an enlarged circle of investigators and a more thorough knowledge of the process, been successfully treated in large tonnage.

The statement made in previous editions that bornite and chalcocite were difficult of treatment was strictly true at the time, but these two minerals are now being successfully concentrated. A recent application of flotation to native sulphur is of interest, and considerably widens the scope of the process. The treatment of partly oxidized ores of copper and lead may be expected in the near future. It would seem at the present time a justifiable prophecy that flotation methods of concentration will in the not distant future very largely displace gravity methods.

PATENTS.

The last two years have yielded an average of about one patent per week on the subject of flotation processes, but one gropes hungrily through this huge mass for a really new idea. The inventors of the processes described in most of these patents have surely approached the subject blindly, and have not taken the trouble to read the patents which constitute the prior art. The temptation is strong to cite examples, but it is best to refrain from usurping the functions of the Courts. Of the list given below, it is necessary to mention favourably, however, the inventions of Callow and Wood, on account of the practical application which has been given to their ideas.

The following list contains a few patents which were overlooked in Chapter II., and a fairly complete list of the patents granted in recent years :

British.

Robson & Crowder, No. 2,538 of 1895 ; separating minerals by the use of soapy water and an oil.

Guillaume Daniel Delprat, No. 26,280 of 1902 ; use of nitrate of soda for flotation.

R. E. Saunders, No. 21,398 of 1905 ; a pneumatic apparatus for separating minerals by means of baffles, against which the ore is drawn by suction.

Elmore & Elmore, No. 26,821 of 1907 ; improvements in apparatus.

Frank Burnett Dick, No. 17,735 of 1910 ; an improved method of treating silicious zinc ores.

Henry Howard Greenway, No. 18,943 of 1910 ; improvements in the concentration of copper ores.

Henry Howard Greenway, Nos. 21,856–7 of 1910 ; improvements in the concentration of ores.

Greenway & Lavers, No. 22,973 of 1910 ; improvements in the concentration of ores.

Edward Hoit Nutter, No. 23,949, 1910 ; improvement in ore concentration.

Murex Magnetic Co., No. 13,208 of 1911 ; improvement.

Murex Magnetic Co., No. 18,189 of 1911 ; improvement.

Chapman & Tucker, No. 28,929 of 1911 ; improvement.

James Hebbard, No. 15,546 of 1912 ; apparatus.

Broadbridge & Howard, No. 25,490 ; apparatus.

Minerals Separation, Ltd., No. 27,323 of 1912 ; improvement.

T. R. Forland, No. 7,107 of 1913 ; treatment of complex sulphides.

H. W. Greenway, No. 11,471 fo 1913 ; improvement.

T. W. Owen, No. 16,141 of 1913 ; differential flotation.

Lowry & Lavers, No. 16,302 of 1913 ; process.

J. D. Wolf, No. 18,351 of 1913 ; process.

G. A. Chapman, No. 18,937 of 1913 ; process.

A. H. Higgins, No. 21,650 of 1913 ; improvement.

E. J. Horwood, No. 28,604 of 1913 ; process.

Minerals Separation, Ltd., No. 1,368 of 1914 ; selective separation.

Minerals Separation, Ltd., No. 17,327 of 1914; improvement.

Minerals Separation, Ltd., Nos. 19,373–4; improvement.

A. H. Higgins, No. 19,855; improvement.

Leslie Bradford, No. 21,880 of 1914; differential flotation.

New Jersey Zinc Co., No. 23,626 of 1914; process and apparatus.

Minerals Separation, Ltd., No. 8,746 of 1915.

United States.

Alfred E. Jones, No. 267,351; process for obtaining float gold.

Axel W. Nibelius, No. 486,495; process of floating graphite.

Robson & Crowder, No. 575,669; duplicate of English patent.

Denis Gale, No. 655,338; separating apparatus.

Henry Peareth Hawden Brumell, No. 678,860; separating apparatus.

John H. Davis, No. 679,473; apparatus for graphite.

Alexander A. Allen, No. 688,279; separation apparatus.

Arthur J. Moxham, No. 689,038; separation in a heavy liquid.

John W. Wolf, No. 725,609; apparatus.

Charles F. Wheelock, No. 734,641; apparatus for dry graphite.

Arthur De Wint Foote, No. 744,322; use of petroleum and lime on surface of concentrator.

Jamieson & Odling, No. 750,034; use of chlorine as a cleaning agent.

Arthur E. Cattermole, No. 763,259; duplicate of British invention.

Virginia Tunbridge, No. 777,159; apparatus.

Arthur E. Cattermole, No. 777,274; process.

Goyder & Laughton, No. 784,999; apparatus.

Orr & Finley, No. 790,913; apparatus.

Benjamin William Rice, No. 792,617; apparatus.

James D. Darling, No. 795,823; apparatus.

Charles H. Ward, No. 799,696; roasting ores.

John W. Littleford, No. 806,770; process.

Alfred Schwarz, Nos. 807,501–2–3–4–5–6; six methods based on the selective action of oily substances.

Archibald R. Livingston, No. 808,945; process.

Edwin C. Pohle, No. 811,085; process of roasting and cyanide treatment. (See Bulletin School of Mines, Missouri, Jan., 1916, p. 71).

John Henry Davis, No. 816,303; graphite separator.

Fred B. Finley, No. 822,515; apparatus.

Edmund B. Kirby, No. 838,626; apparatus.

James Francis Latimer, No. 851,599; apparatus.

Arthur Penrhyn Stanley MacQuisten, No. 865,260; apparatus.

Dudley Hiram Norris, No. 873,586; apparatus.

Jacob David Wolf, No. 899,149; apparatus, oiled belt.

Jacob David Wolf, No. 899,478; process of treating on an oiled travelling surface.

Sulman & Sulman, No. 902,018; apparatus.

Marcus Ruthenburg, No. 933,491; process.

A. S. Ramage, No. 949,002; selective flotation.

Theodore Jesse Hoover, No. 953,746; apparatus.

Lockwood & Samuel, No. 956,381; process.

James Dunstone, No. 956,800; process.

Alexander S. Ramage, No. 967,671; process based on successive rises in temperature.

Henry Azor Wentworth, No. 970,002; process.

Samuel K. Behrend, No. 973,467; apparatus.

Alfred Arthur Lockwood, No. 996,491; process.

Francis I. du Pont, No. 1,014,624; heavy solution process.

Benjamin Sedgely Smith, No. 1,014,977; apparatus.

Edward James Horwood, No. 1,020,353; process of separating sulphides.

William Sullivan Blaine, No. 1,032,732–3; apparatus and process of separating rubber by flotation.

Alfred Arthur Lockwood, No. 1,043,850–1; processes.

Thomas John Greenway, No. 1,045,970; process.

Carl Schick, No. 1,055,495; process.

Alexander Herbert Smith, No. 1,058,111; apparatus.

Francis I. du Pont, No. 1,064,459; process with heavy liquid.

Francis I. du Pont, No. 1,067,410; apparatus for heavy liquid process.

Nutter & Lavers, No. 1,067,485; process.

Frank W. Pugsley, No. 1,071,791; process with chlorine gas.

Henry Ellsworth Wood, No. 1,071,850; apparatus.

Chapman & Tucker, No. 1,079,107; process.

Hermann Alexander Brakelsberg, No. 1,080,886 ; apparatus.

Charles Henry Brown, No. 1,081,360 ; apparatus.

Broadbridge & Howard, No. 1,084,196 ; apparatus.

Allen Crawford Howard, No. 1,084,210 ; apparatus.

Henry Ellsworth Wood, No. 1,088,050 ; apparatus.

Nutter & Hoover, No. 1,093,463 ; apparatus.

Joseph T. Terry, No. 1,094,760 ; preliminary flotation treatment with hydrogen sulphide.

Henry Howard Greenway, No. 1,099,699 ; process.

Leslie Bradford, No. 1,101,506 ; differential flotation of sulphides.

Greenway & Lowry, No. 1,102,738 ; process with chromium salts.

Chapman & Tucker, No. 1,102,873–4 ; preliminary preparation of emulsion.

John M. Callow, No. 1,104,755 ; porous bottom apparatus.

Francis I. du Pont, No. 1,106,195 ; apparatus.

Edward James Horwood, No. 1,108,440 ; preliminary treatment for differential flotation.

William Sydney Stevens, No. 1,116,642 ; process.

John M. Callow, No. 1,124,853 ; apparatus.

Callow & Kelly, No. 1,124,855 ; apparatus.

John M. Callow, No. 1,124,856 ; apparatus.

John M. Callow, No. 1,125,897 ; process.

Joseph W. Emerson ; No. 1,126,965 ; process.

Bernard MacDonald, No. 1,134,690 ; apparatus.

Charles E. Pork, No. 1,136,485 ; apparatus.

Benjamin Sedgley Smith, No. 1,136,622 ; apparatus.

Raymond F. Bacon, No. 1,140,866 ; process.

John M. Callow, No. 1,141,377 ; apparatus.

Henry Lavers, No. 1,142,821 ; process.

John W. Littleford, No. 1,142,822 ; improvement.

Appleqvist & Tyden, No. 1,143,797 ; process.

Archibald R. Livingston, No. 1,147,633 ; process.

Arthur J. Moxham, No. 1,151,117 ; heavy liquid method.

Higgins & Stenning, No. 1,155,815 ; apparatus.

Arthur Howard Higgins, No. 1,155,816 ; apparatus.

Thomas MacKellar Owen, No. 1,155,836 ; apparatus for differential flotation.

Louis Albert Wood, No. 1,155,861 ; process.

George C. Stone, No. 1,156,041 ; apparatus.

Robert S. Towne, No. 1,156,382 ; process.

Thomas MacKellar Owen, No. 1,157,176 ; process for selective flotation.

Lewis G. Rowand, No. 1,159,713 ; process.

Thomas A. Janney, No. 1,167,076 ; apparatus.

Dudley H. Norris, No. 1,167,835 ; apparatus.

Esten Beeler, No. 1,167,619 ; bubble-making machine.

Arthur Howard Higgins, No. 1,170,637 ; improvement.

Edward Hoit Nutter, No. 1,170,665 ; improvement.

Kollberg & Kraut, No. 1,174,797 ; apparatus.

Thomas J. Lovett ; No. 1,175,966 ; apparatus.

Gayford & Crerar, No. 1,176,441 ; process.

SMELTING AS AFFECTED BY NEW CONCENTRATION.

The effect of a large tonnage of flotation concentrates on various departments of the smelting industry is becoming most marked.

The advent ten years ago of a large amount of zinc concentrates from Broken Hill of a quality theretofore unknown, completely changed the practice of zinc metallurgy in Europe. The German smelters were quick to seize the opportunity presented by a large tonnage of material of a uniform grade. They took the whole of it and adapted their practice to the needs of the material, and were able, as a result of this manœuvre, to seize the whole of the zinc smelting in Europe.

Flotation concentration, because of its adaptability to slime treatment, which yields in many cases a concentrate of extreme fineness, has thereby given rise to considerable difficulty in the roasting department. Smelters, therefore, try to exact a penalty for fineness beyond a certain degree, the penalty being designed to cover the increased costs due to roasting difficulties.

In the treatment of copper ores some profound alterations in smelting methods have of necessity been made, notably at Anaconda, and others will, no doubt, arise. A case has been known where the concentrate from ordinary gravity methods has involved the use of large amounts of flux, whereas the concentrate derived by flotation methods was practically self-fluxing.

Some notable innovations in gold metallurgy are imminent. In Colorado the tailings from gold mills, which contain gold in the form of a telluride, are now being successfully concentrated ;

these concentrates will in turn be either smelted or cyanided. The cyanidation of flotation concentrates without roasting presents some difficulties, due to the presence of organic matters. These difficulties are serious, as the tendency is to produce saponification of the oils used to produce the concentrate.

OILS FOR FLOTATION.

The early period of the application of flotation to ores may be characterized as the oleic acid days. Another name for oleic acid is red oil, and it is a by-product of candle and soap works. Oleic acid was a good frothing agent, but required a high temperature to be maintained in the pulp, and required the use of a large quantity of sulphuric acid to prevent saponification and emulsion of the oil in the presence of the ore.

Oleic acid was succeeded by eucalyptus oil, which is now used on a large scale in Australia ; this was the discovery of Henry Lavers. Although eucalyptus oil costs more per gallon than oleic acid, much less of it per ton of ore is used, and further savings in sulphuric acid and decreased temperature are also effected. Australia is the native home of the eucalyptus, but although there is a fair supply of oil for local use, there is little likelihood of any large export trade being built up.

American users of flotation processes were, therefore, forced to seek for other sources of frothing agents. This has interested the manufacturers of oils, and they have expended considerable energy in the search for substitutes for eucalyptus oil. They have been successful to a high degree, and by a careful investigation of their various distillation fractions have produced what the American mines have needed. Various fractions from the destructive distillation of pine wood have been especially useful in this connection.* The wood used is the very resinous pine of the South Atlantic and Gulf Coast. The dead wood only is used, that from which the sap has rotted, leaving the resinous heart wood. This, if of good quality, yields an average of a thousand pounds of oils per cord. The wood is used in regular four-foot cord wood form, and is distilled in a very modern type of apparatus—the latest improvement in destructive distillation work.

A sketch of this apparatus and flow sheet are shown in Fig. Y. The retorts are of heavily reinforced construction, with fifteen-inch walls, and are ninety-six feet long, holding eleven cars of wood

* *Bulletin* on Pine Flotation Oils, by the Pensacola Tar and Turpentine Co., Gull Point, Florida, 1916.

of one cord capacity each. These cars are of all-steel construction, and are left in the retort with the wood throughout the process. Retorts are heated with internal flues from furnaces fired with fuel oil and the combustible gases formed from the destructive distillation of the wood and its resinous content. The wood is subjected to temperatures which distill all of the resinous material, leaving nothing but charcoal on the cars, of which there is some thirty-five to forty bushels per cord. By careful control of temperature there is produced from the bottom of the retorts some 250 pounds or more of pitch per cord of wood, thereby yielding a crude oil from the condensers with a lower pitch base than most other destructive distillation processes. This is important, as experience has shown that heavy pitch base oils are gangue lifters.

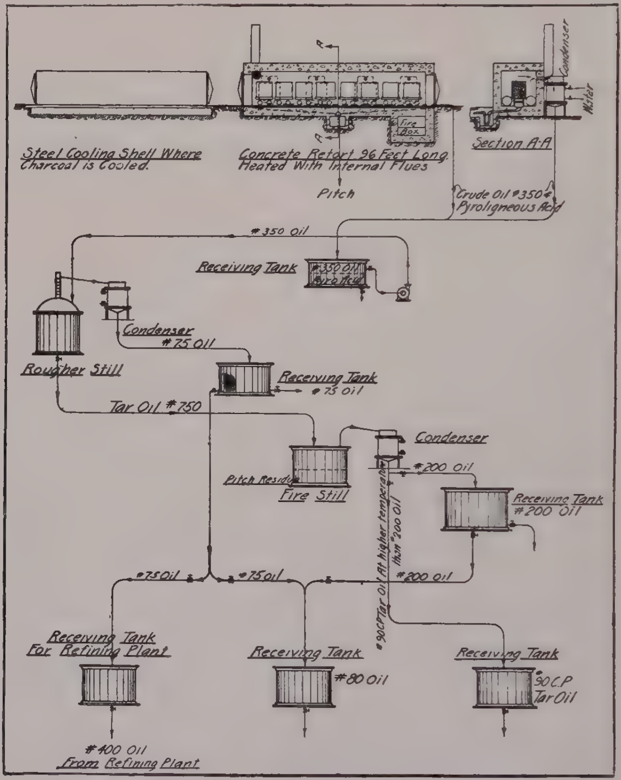

FIG. Y.—Pensacola Process for Producing Pine Oil by Distillation of Wood.

The process is as follows: After a period of complete distillation the doors of the retorts are opened, a chain is attached to the pulling cable at one end and to the train of cars of wood at the other, and the eleven cars of charcoal are pulled into the cooler at the same time that the eleven fresh cars of wood are pulled into the retort. These eleven fresh cars have been standing on the loading track in front of the retorts, and the job of pulling the trains and closing up the retort again only occupies a few minutes. The doors, which are fitted with air-tight joints, are closed, fires again turned on, and in a very short time the condensers begin to flow.

The liquor coming off from the condensers is composed of water, crude pine oil, and pyroligneous acid. This acid water, containing about 4% of acetic acid, is run to waste after settling. The crude oil which contains the crude wood turpentine, crude pine oils, wood creosote oils and tar oils, is pumped to a large roughing-off still. This large roughing-off still contains copper heating coils and a system of steam jets. The lightest product made by the destructive distillation of this resinous pine wood is a wood naphtha. Though an excellent selective agent, it is too volatile to be used as a flotation medium, and the small quantity contained is rapidly removed by the aid of the steam coil alone. When this is driven off distillation is continued by using both the steam jets and the coil, the crude wood turpentine, pine oil, and a small quantity of wood creosote oil being driven off.

The steam still will not economically drive off any of the higher temperature and heavier oils, so the still is, after a time, emptied into a large copper fire still, where the temperatures are raised, and in the first instance the wood creosote is removed, and later the temperatures carried up and the tar oils distilled off.

Tests on the various products from Southern pine are given in the table below; the constants shown with the list of oils may vary slightly, but probably not enough to affect their value as frothing agents. Being mostly crude products, they do not have the same accurate and positive constants that well refined oils have. With the exception of the No. 15 and No. 1,580, they are explained in the flow-sheet. The No. 15 is a thin rosin oil, spoken well of as a good frothing agent, and the No. 1,580 is a mixture of this and the No. 80, and is on many ores an excellent selective agent, as well as a good frothing agent.

The polymerization test on these oils was made as follows: Place 20 c.c. of concentrated sulphuric acid in a graduated narrow neck Babcock flask, and place in ice water to cool. Add slowly 5 c.c. of the oil to be tested. Gradually mix the contents, cooling from time to time, not allowing the temperature to get above 60° C. When it no longer warms up on shaking, agitate thoroughly. Place in water bath and heat from 60° to 65° C. for about ten minutes. Keep agitating four or five times during the heating. Cool to room temperature, and fill flask with concentrated sulphuric acid until unpolymerizable oil rises in neck. Allow to stand 12 hours or more for light oils, and 48 for heavy, and read unpolymerizable matter in graduated neck for percentage. All of the organic oils contain some unpolymerizable matter which should be deducted.

LIST OF OILS AND CONSTANTS.

	Sp. Gr.	Dist. Pts.	Rf. Indx.	Vis.	Non-Pol.
No. 75 Crude Wood Turpentine ...	.887	65–217	1.456	.9	10-12%
No. 80 Crude Pine Oil	.911	70–232	1.4894	1.1	8%
No. 90 Redistilled Pine Tar Oil ...	.982	160–368	1.5636	5.8	
No. 200 Refined Wood Creosote Oil	.965	105–275	1.5096	1.7	7-8%
No. 400 Crude Wood Creosote Oil ...	1.025	190–360	1.4977	2.9	
No. 15 Special Thin Rosin Oil ...	1.017	170–368	1.5631	6.1	
No. 350 Special Crude Pine Wood Oil	1.019	70–345	1.525	2.9	4%
No. 1580 Combination Pine Oil ...	.980	85–352	1.5361	2.3	

A research into the products from the destructive distillation of various other woods will, no doubt, produce materials of equal interest. This field for investigation is largely unoccupied at present, and is a very attractive one. The notes under the following sub-heading have a bearing on the same subject.

SOLUBLE FROTHING AGENTS.

The following remarks on frothing agents apply only to the operation of a flotation process where the water used is recovered by settling ponds, tanks, or spitzboxes, and returned to the process ; in other words, a closed circuit.

When the relatively insoluble substances, such as oleic acid, mineral oils, animal oils, and certain tar products are used as frothing agents it is not surprising that it is necessary to add to each ton of ore treated a given amount of these substances. It is reasonable to suppose that the oils selectively adhere to the sulphides, and are thus removed from the pulp circuit. At any rate, these oils disappear, and even though the liquid in which the process is carried out is recovered and returned to be used over again, it is necessary to constantly add a given amount of oil for each ton of ore treated, no matter how often the water is returned to the treatment.

In the case of soluble frothing agents, however, such as eucalyptus oil, essential oils in general, phenols, alcohols, and others, the theory of selective adhesion fails. It is inconceivable that any selective tendency between the sulphides and these oils can operate to remove the latter from solution; this would not fit in with our ideas as to the nature of solution. Nevertheless, these soluble frothing agents disappear from the solution, so that each time the water is used a small portion of the frothing agent is added for each ton of ore treated. What makes these substances disappear is an interesting question, and for the present no opinion will be expressed. It was conceived in 1914 that some soluble substance, having melting and volatilization points much higher than the essential oils might be usefully tested, the idea being that a substance might be discovered which would be an effective soluble frothing agent, and at the same time one which would not disappear and have to be renewed each time the solution was returned to the plant. If such a soluble frothing agent could be found the consumption of the agent would be cut down to a minimum, as it would be necessary to use only enough of the agent to standardize what fresh water was added to make up losses by evaporation and seepage. G. J. Frost, chief chemist in the author's laboratory, undertook the research necessary to elucidate this idea, and after casting widely through large divisions of organic chemistry selected certain derivatives of turpentine as probably offering a successful result. Mr. Frost joined the British Army as Second Lieutenant of the 7th Suffolk Regiment, and was unfortunately killed in action on September 9, 1915. His research at the time of its adjournment carried considerable promise of success; and although it was incomplete and fragmentary, it is thought to be of sufficient value to justify publication practically as he left it.

Lieutenant Frost's work, compiled and arranged from his laboratory notes, was as follows: Pinene is a constituent of all the known species of turpentine. American turpentine (*Pinus palustris*) and French turpentine (*Pinus maritima*) yield the most pinene; in the American turpentine pinene forms about 90% of the whole. The pinene fraction is the one which distills between 155° and 160° C. When dry hydrochloric acid is passed into well cooled pinene, pinene hydrochloride is formed, which crystallizes out. Theoretically the whole mass should become solid, but owing to the presence of limonene, dipentene, etc., only a portion solidifies. The solid and the liquid remaining with it, together or separate, are excellent frothing agents in flotation concentration. The solid has a melting point of 50° C. Observations on the solubility of pinene hydrochloride were made by taking 3,000 cc. of water containing 4 cc. of concentrated sulphuric acid, which is the amount used in small flotation tests, and corresponds to 15 lb. of acid per ton of ore. This was warmed to 50° C. with one gramme of solid pinene hydrochloride. The smell was observed to be more like natural camphor after this treatment. A portion of a compound which condensed upon the neck of the flask, was removed and dried, and the melting point determined at about 120–130° C. The melting points of pinene hydrochloride and camphor are 50° and 175° C. respectively, so it seems that a part of the pinene hydrochloride was hydrolysed to borneol ($C_{10}H_{16}HCl$ to $C_{10}H_{16}HOH$).

TEST A.—A preliminary guiding series was run on South Extended ore to see whether eucalyptus oil (one of the best soluble frothing agents) repeats its results without renewal time after time and to what extent. The conditions were as follows :

5,000 cc. water.
$\frac{1}{2}$ gramme eucalyptus oil.
15 lb. H_2SO_4 per ton.
40° C. temperature.
Speed of mixer, 2,000 r.p.m.
2 lb. H_2SO_4 added after each test.
Solution was recovered after each test, and used in subsequent test.
500 grammes ore used in each test.

The following series of results were obtained :

TEST NO.	WEIGHT OF CONCENTRATE. GRAMMES.	ASSAY OF CONCENTRATE. % ZN.	RECOVERY OF ZINC. %
F 53	347	36.70	97·4
F 54	330	37.80	95·2
F 55	318	40.11	97·4
F 56	386	39.06	85·3
F 57	192	38.12	55·9
F 58	153	38.85	45·4
F 59	Solution dead — no froth.		

Conclusion.—Eucalyptus oil used on this ore repeats four times, and then rapidly loses power, and on the seventh trial will no longer produce any froth.

Test B.—A series under similar conditions was then carried out, using pinene hydrochloride instead of eucalyptus oil.

5,000 cc. water.
1 gramme solid pinene hydrochloride.
All other conditions equivalent to above test.

Test No.	Weight of Concentrate. Grammes.	Assay of Concentrate. % Zn.	Recovery of Zinc. %
F 32	145	42.66	89.7
F 33	137	43.22	85.8
F 34	137	41.10	81.1
F 35	81	43.35	50.9
F 36	141	41.90	85.6
F 37	140	42.90	87.1
F 38	130	42.20	79.5
F 39	120	40.80	71.0
F 40	114	40.20	66.4
F 41	120	40.32	70.1

The first three of the above tests worked well, but the fourth was not so good, and the solution was found to have lost its acidity. This was corrected for the balance of the series, and the froths up to the last were strong, fine-grained, and permanent. From F 38 to F 41 the tests were handicapped by a shortage of solution owing to the loss in tailing, leakage, and evaporation.

Conclusions.—Comparing this with the eucalyptus series, we have a repetition of fair results for about eight times, and it is believed this could have been done much oftener if a larger stock of solution had been used to commence with. The pulp had become too thick in the last three tests, and the froth did not come up as before.

Test C.—A guide test series was next run under the same conditions, using American pine oil.

Test No.	Grammes Concentrate.
G 10	336
G 11	320
G 12	221
G 13	120
G 14	No froth.

This series was not assayed, as the weight of concentrate shows the position as to repeating results.

Test D.—A series was now run, using iso-borneol as the frothing agent, other conditions except those stated below being equal to the previous tests. Better arrangements were made for the recovery of solution so as not to run short.

4,000 cc. water.
0.4 gramme iso-borneol (dried on filter paper).

The filtrate from the first test was used for the second, and so on throughout the series. To the second and succeeding tests acid was added at the rate of 2 lb. per ton.

The first eleven tests were made on South Extended ore, and when this was exhausted Broken Hill Proprietary ore was substituted.

Test No.	Grammes Concentrate.
F 79	324
F 80	275
F 81	285
F 82	285
F 83	275
F 84	280
F 85	282
F 86	275
F 87	285
F 88	285
F 89	275
F 90	148
F 91	149
F 92	145
F 93	145
F 94	140
F 95	142

With the seventeenth run the pulp began to show signs of becoming too thick, due to loss of solution in filtering, etc. The solution showed no sign of losing frothing power. In all the tests the tailings were quite clean and free of sulphides, and the concentrates were of excellent appearance.

Lieutenant Frost's work ended here, at a most interesting point. His test on iso-borneol was a side venture at a hazard, while intending to carry out a more extended investigation of pinene hydrochloride. The tests on both these substances are of exceptional interest when compared with the results on eucalpytus and pine oils. The repetition shown in the iso-borneol series justifies further research, and the results are here given in the hope that the investigation may be further proceeded with.

WATER JETS.

Flotation processes may be said to consist, in the main, in the act of adding to a finely crushed ore water and one or more modifying agents, which agents alter the surface tension qualities of the water, and then bringing into contact with the particles of crushed ore, air or other gas in a state of fine subdivision. Some of the methods whereby this gas, in a fine state of subdivision, is brought into contact with the particles of ore are :

(*a*) Generating the gas in place by chemical or electrolytic means.

(*b*) Agitating the mixture of ore and water violently, whereby the large volume of finely subdivided air is whipped into the pulp.

(*c*) Injecting air into the pulp by means of nozzles, and through perforated media in the bottom or sides of a tank.

(*d*) Subjecting the ore pulp to a vacuum, whereby the air, which is dissolved in the water at ordinary temperature and pressure, is released.

(*e*) By allowing the pulp to cascade from one vessel to another, as a result of which an agitation is secured, which includes a small amount of fine air bubbles.

The result of all the above methods is that these gas bubbles are released in the pulp, and selectively adhere to certain particles of the ore and float them to the surface, where they can be removed as a froth, the froth having qualities which render it more valuable than that portion of ore which does not float.

A careful study of the behaviour of a fine jet of water (or water modified as to its surface tension qualities by the introduction of various agents) plunging through the surface of a larger body of water (or such modified liquid), reveals some important observations bearing on the subject of ore flotation concentration. For the purpose of study, a vessel containing clear water, modified as to its surface tension qualities by eucalyptus oil, or some other substance, has arranged above it a fine nozzle carrying the same or other liquid, the jet being so arranged that it strikes the water approximately vertical to the plane of the horizontal surface of the water at rest in the vessel, and the nozzle so arranged that it can be raised and lowered at will for purposes of observation. It will be observed that the jet carries down into the body of the liquid in the main vessel, bubbles of air. Observation of a small jet arranged to aerate water in a goldfish globe first brought these matters under consideration.

Whatever the distance of the nozzle from the surface of the liquid, within certain limits, there are two distinct sizes of bubbles: (*a*) a very small size group, which float leisurely through the liquid; and (*b*) a larger size group, which come at once to the surface and break. These very fine (*a*) bubbles are the ones which are useful generally in ore concentration, and their size is independent of the height of the nozzle. They are always about the same size, say about 1/10th mm., as far as the eye can judge; but if accurate measurements could be taken of this small-sized group, it would probably be found they did vary slightly in size, and that this variation was dependent on the surface tension of the liquid. While the size of the individuals in this small-sized group is independent of the height of the nozzle, the number of them is not.

When the nozzle is at a considerable distance, say twelve inches, from the surface of the liquid in the vessel, the large group (*b*) bubbles are, say, $\frac{1}{4}$-mm. in diameter. As the nozzle is lowered, the bubbles of this group decrease in size, until finally there arrives a point where the jet, as it breaks through the surface of the liquid in the vessel, carries down only bubbles in an extremely fine state of subdivision, or approximately that of the small group only. These small bubbles are so fine that they do not immediately rise to the surface, but float around for a time within the main body of the liquid, rising to the surface in a leisurely manner, as compared with those of the larger group. It is also interesting to observe that there is not a steady and uniform decrease in the number of the bubbles of the large group, as the distance between the nozzle and the surface of the liquid is decreased.

When the nozzle is high up above the water, the jet, by its impact with the surface, produces a 'chugging' or 'gurgling' sound, and the bubbles vary from 1/16 to $\frac{1}{2}$ inch in diameter. As soon as the nozzle is lowered to a certain point, the gurgling ceases, and the noise becomes a sharp hiss. There is a definite relationship between the height of the nozzle, the surface tension of the liquid, the velocity of the jet, and the temperature of the liquid, and the size and number of the bubbles and the noise.

As the nozzle is further lowered toward the surface of the water, there arrives an approximate point where the jet enters the water cleanly, without any disturbance on the surface ; no noise is produced, and no air bubbles of any kind are included.

These two points—the point of the hiss, and the point where bubbles cease to be carried down—are capable of approximate measurement, and would seem to offer a method for study of surface tension phenomena. The apparatus should be so arranged that there will be as few as possible unknown factors, such as variable pressure in the nozzle, etc.

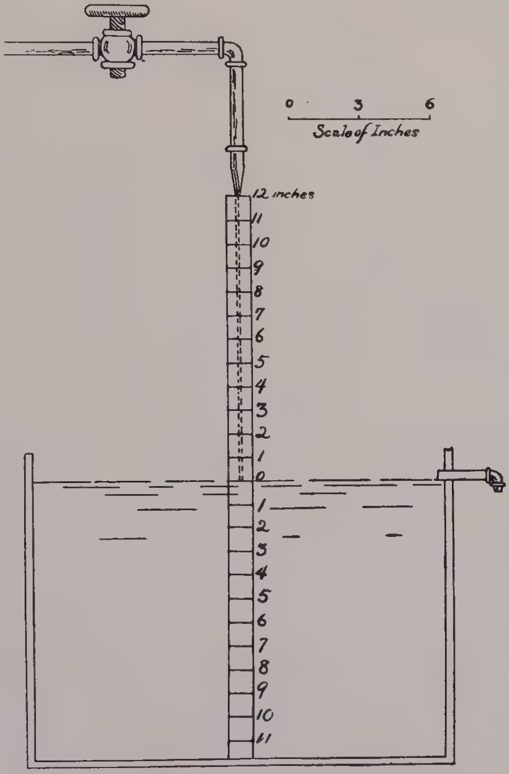

FIG. Z.—Bubbles carried into Liquid by Water-jets.

The apparatus is here shown in Fig. Z, and the method is suggested in the hope it will be made use of in the study of the effects of oils and other substances used for modifying the molecular qualities of liquids used in flotation. Useful suggestions in connection with such a study will be found in an article by C. Terry Durell, *Met. & Chem. Eng.*, Vol. XIII., No. 12, p. 714.

The above notes were written in December, 1914, and laid by for future reference. Since then a patent has appeared which is based on the same principles.

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- p. 6, Sale of Australian Zinc Concentrate in America, 10 lines.
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- p. 87, Colloids and their Importance.
- p. 109, Colloids in Ore Dressing, A. W. Allen.

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- p. 24, Australia, 1 col.
- p. 79, Flotation Processes during 1913, by Edward Walker, 2 cols.
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- p. 3, Minerals Separation *v.* Miami Copper Co., ½ col.
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